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A Survey of New Technology for Cockpit Application to 1990's Transport Aircraft Simulators

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A SURVEY OF NEW TECHNOLOGY FOR COCKPIT APPLICATION TO 1990'S TRANSPORT AIRCRAFT SIMULATORS

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SUMMARY

The transport aircraft of the 1990's will use a number of systems not found on today's aircraft, including MLS, 4-D Nav, CDTI, and DABS. While these systems improve efficiency and safety, they give rise to new problems in the design of aircraft and aircraft simulators. This report investigates two of these problems - inter-equipment data transfer, both on-board the aircraft and between air and ground; and crew-equipment communication via the cockpit displays and controls. Inter-equipment data transfer is discussed in Chapter I in terms of data bus and data link requirements. Crew-equipment communication is discussed in Chapters II and III regarding the availability of CRT display systems, and of software-controllable touch panels.

To study the crew-equipment communication problem, both the National Aeronautics and Space Administration and airframe manufacturers are currently developing advanced concepts simulators; certain ones of these will use large-screen color displays and touch panels. Large flat panels may ultimately be used in the cockpit. Since suitable flat-panel displays are not presently available, large-screen shadow mask CRTs will be used in the simulator until flat-panel technology matures.

I. Data Bus and Data Link Requirements

This brief study is a preliminary investigation of the data bus and data link requirements for a 1990's aircraft and an investigation of the adequacy of presently defined data buses and DABS to fulfill these requirements. A comparison of presently defined ARINC and military data buses was also made and a typical avionics equipment complement for a 1990's aircraft was postulated.

The investigation showed that the presently defined ARNIC 429 and 453 data buses are adequate for all expected requirements for intra-aircraft data flow. MIL-STD-1553B multiplex buses will accommodate the basic equipment data flow on a single set of redundant buses, but will require separate buses for such wide-band signals as radar video.

For on-board computation, the distributed processor concept has a definite advantage over the centralized concept, particularly from a data rate standpoint.

DABS appears adequate for most needs, but additional detailed operational analysis and data rate studies are needed to define what data is essential and how best to use available data.

An investigation of fiber optics for data bus use showed that its principal application will be in flight critical areas which are sensitive to EMI and in sumulator use.

II. Large-Screen Color CRT Displays

Large-screen color Cathode Ray Tube (CRT) graphics display system vendors were surveyed to determine the availability of systems

and components for a multi-function cockpit display. The driving requirement is the ability to display flight instruments. These Displays require a very high resolution system to provide adequate display detail and full color for standard flight instrument presentation. These requirements dictated selection of a high resolution three-gun CRT system. Several vendors were identified who have systems currently available that can satisfy these requirements, including Aydin Controls, Ramtek, Genisco, Ikonas Graphics, and Smiths Industries. Their systems are described.

Displays which do not include the primary flight instruments can be configured with less stringent requirements and lower resolution systems will suffice. Many additional vendors have such systems and several are listed in Appendix II.A.

It is recommended that the practicality of incorporating vector as well as raster-scanning in available commercial large-screen color monitors be investigated. A set of requirements for the display system should be developed and the processor adequacy of available systems evaluated against these requirements. Feasibility of processor modifications should be determined if necessary to meet the requirements. Procurement or development of the system should then proceed based on these findings.

III. Software-Controllable Touch Panels

A survey was conducted of the availability of software-controllable touch panels for use in the flight station simulator. Applications considered were simple option selection, decision tree option selection, paging or long-list option selection, alpha-numeric data entry, and point location on maps.

Touch panels were discussed in terms of their two basic elements, the display surface and the touch locator. The CRT display surface has the advantage of full color capability, adequate brightness, and complete display flexibility. The flat panel display surface has the advantage of shallow depth, little or no parallax, and lower voltage requirements than the CRT, but is not available with programmable color or adequate resolution. The liquid crystal display is the only flat panel which is useful in high ambient light.

Beam interruption and line selection side switch units are widely used and are available in military-qualified versions. The voltage gradient-CRT touch panel is also in use and features a curved surface which reduces parallax due to CRT face plate curvature. These types are suitable for near-term simulator use for option selection; the side-switch type does not provide the flexibility for map location.

When used in a fully integrated flight station, the touch panel will be a critical component since it will provide input for many different systems; adequate backup facilities should be provided.

LIST OF ACRONYMS

4-D NAV	X,Y,Z, Time Navigation
A/C	Aircraft
A/D	Analog-Digital (Conversion)
A/N	Alphanumeric
ADI	Attitude Director Indicator
ADF	Automatic Direction Finder
AEEC	Airline Electronic Engineering Committee of ARINC
AIDS	Advanced Integrated Display System
ALEC	Altitude Echo
AM	Amplitude Modulation
ARINC	Aeronautical Radio, Incorporated
ATC(S)	Air Traffic Control system
ATCRBS	Air Traffic Control Radar Beacon System
ATIS	Air Traffic Information System
BCAS	Beacon Collision Avoidance System
BCD	Binary Coded Decimal
BIT	Built-in Test
BNR	Binary
CA	Collision Avoidance
CAS	Collision Avoidance System or Computed Air Speed or Command Augmentation System
CDTI	Cockpit Display of Traffic Information
CPU	Central Processing Unit
CRT	Cathode Ray Tube
DABS	Discrete Address Beacon System
DADC	Digital Air Data Computer

DADS	Digital Air Data System
Deg.	Degrees
DMA	Direct Memory Access
DME	Distance Measuring Equipment
EADI	Electronic Attitude Director Indicator
EFIS	Electronic Flight Instrument System
EHSI	Electronic Horizontal Situation Indicator
EL	Electroluminescent (Panel)
ELM	Extra Length Message
EMI	Electromagnetic Interference
EPROM	Erasable Programmable Read-only Memory
FAA	Federal Aviation Administration
FM	Frequency Modulation
FMC	Flight Management Computer
FMS	Flight Management System
Ft.	Feet
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
HF	High Frequency
Hz	Hertz
HSI	Horizontal Situation Indicator
HUD	Head-Up Display
ICP	Integrated Control Panel
ID	Identification Code
IFR	Instrument Flight Rules
ILS	Instrument Landing System

INS	Inertial Navigation System
I/O	Input/Output
IPC	Intermittent Positive Control
IR	Infrared
IRS	Inertial Reference System
IU	Interface Unit
K	Kilo (1000 or 1024)
Kbps	Thousand Bits Per Second
KHz	Thousand Hertz
Kph	Kilometers per Hour
Kts	Knots (Nautical Miles per Hour)
LaRC	Langley Research Center
Lat.	Latitude
LCD	Liquid Crystal Display
LED	Light Emitting Diode
Long.	Longitude
Mbps	Million Bits Per Second
MFD	Multifunction Display
MHz	Million Hertz
MSAW	Minimum Safe Altitude Warning System
MLS	Microwave Landing System
NASA	National Aeronautics and Space Administration
Nom.	Nominal
N. mi.	Nautical Mile
ns	Nanosecond
PA	Public Address

P-P	Peak to Peak
RAM	Random Access Memory
REL	Relative
RGB	Red-Green-Blue
RNAV	Area Navigation
RZ	Return to Zero
SELCAL	Selective Calling
T. O.	Take Off
TBD	To Be Determined
TTL	Transistor-Transistor Logic
TV	Television
UHF	Ultra-High Frequency
us	microsecond
V	Volts
VFR	Visual Flight Rules
VHF	Very High Frequency
VHS	Very High Speed
VN	Vertical Navigation
VOR	VHF Omni Range or Visual Omni Range
Wx	Weather

INTRODUCTION

The forecast for 1990's aircraft is for an increasing number of systems and devices. This trend presents two major problems in the design of the aircraft. The first problem is how to communicate data among the various devices and systems. The first chapter by A. P. Holt, Jr. is an investigation into the ARINC and MIL-STD data buses. The second problem is how to communicate all this data to the pilot in a meaningful way. To study this problem, the Lockheed-Georgia Company under contract from NASA is developing a flight station simulator. Among the technologies that are to be used in this simulator are large-screen color CRT displays to present primary flight instruments and touch panel overlays for these screens to replace conventional switch assemblies. In the second chapter, D. O. Noneaker surveys available CRT displays and display systems. L. Walthour reviews the available software-controllable touch panels in the third chapter.

This report is a collection of three independent Lockheed-Georgia reports sponsored by NASA. The use of commercial products or names of manufacturers in this report does not constitute official endorsement of such products or manufacturers, either expressed or implied, by either the National Aeronautics and Space Administration or the Lockheed-Georgia Company.

I. DATA BUS AND DATA LINK REQUIREMENTS
by A. P. Holt, Jr.

BACKGROUND

Interconnection of the various avionics and electronic systems aboard an aircraft has been a difficult and expensive task which in the past has resulted in large wire bundles and a lack of flexibility for future changes.

Looking to the future, additional systems will be added in order to increase airport efficiency, avoid excessive noise, achieve fuel economy, and promote flight safety. Typical of these new concepts are MLS, active flight controls, advanced flight management systems and CDTI. Furthermore, new concepts of distributed processing and redundancy are evolving. These trends tend to make the interconnection task more difficult. In response to this dilemma, digital data bus concepts have been developed for both civil and military aircraft and their use has brought a measure of standardization to the equipment interfacing problem. These bus concepts have become feasible because digital electronics are already used aboard today's aircraft and will be used almost exclusively in the 1990's time frame.

Due to these considerations, questions have arisen as to the adequacy of ARINC buses in future aircraft and the relative merits of the ARINC and MIL-STD-1553B bus concepts. The first aspect of this study is directed at answering these questions regarding intra-aircraft data transfer.

The Discrete Address Beacon System (DABS) is now undergoing testing as a replacement for ATCRBS, and its implementation in the National Air Space is planned for the 1980's. An extended version of DABS will provide channels of digital air-ground communication which will be useful for many functions. Some of these functions such as CDTI represent new potential applications, while other functions will supplant oral air-ground communication as it is used today. Questions have arisen as to the adequacy of extended DABS in the 1990's time period to accommodate the various proposed functions with regard to data rate, update rate, and other factors. The second aspect of this study is directed at answering these questions regarding extended DABS.

The Lockheed-Georgia Company is developing an advanced concepts flight station simulator which is also of interest to NASA for various validation experiments. Some of the simulator equipment such as displays will be similar to that which will be found on actual aircraft. Other equipment will simply be simulated. The various simulator equipment, computers, and consoles could be interconnected by data buses in much the same manner as buses are used aboard actual aircraft. Questions have arisen as to the practicality of this approach, and how the simulator bus structure should differ, if any, from that to be used in the 1990's aircraft. Their objective is to facilitate the simulator development and operation rather than to realistically simulate the operation of the aircraft data buses. The third aspect of this study is to answer these questions regarding the use of data buses in the advanced concepts flight station simulator.

TECHNICAL DISCUSSION

Typical Advanced Transport Equipment List

Two suites of avionics for a 1990's transport aircraft are shown in Table I.1. The "Pyramid" or maximum list includes all current operational systems plus those new systems expected to be operational in the 1990's. This pyramid approach conforms with historical precedence and present practices; i.e., old systems are never abandoned or deleted as new systems are developed. The "Advanced" list omits all older systems whose functions are performed by newer, more advanced systems. The advanced system list was used to evaluate data bus requirements for this study.

DABS Beacon Downlink Data

Table I.2 details the aircraft systems that send data to the DABS beacon for downlink transmission. Since most of these data are required once every four seconds (one ATC ground station scan time), a two-per-second update rate for the data should be adequate. The maximum amount of information required is from the IRS, which originates five data words. Since there are three IRS units, the maximum total number of IRS words required on a once-per-scan basis is 15. The slowest of the ARINC 429 bit rates (12-14-Kbps) will suffice for these data.

From Table I.2 it is seen that the total data transfer required on a once-per-scan basis amounts to less than 160 bits. Actually 13 bits will suffice if the proper data arrangement is used. This

TABLE I.1

TYPICAL PROJECTED AVIONICS FOR 1990'S AIRCRAFT

"PYRAMID" EQUIPMENT LIST	ADVANCED SYSTEMS LIST
VHF Comm (2)	VHF Comm (2)
VCR/ILS (2)	
DME (2)	
H. F. Comm	H. F. Comm
SELCAL	SELCAL
Voice Recorder	Voice Recorder
PA	PA
Intercom	Intercom
UHF Satcom	UHF Satcom
Autoflight System	Autoflight System
MLS (2)	MLS (2)
IRS (2 or 3)	Laser IRS (3)
ADF	
Radio Altimeter (2)	Radio Altimeter (2)
Marker Beacon	
OMEGA	
Weather Radar	Weather Radar
Flight Mgmt System (2)	Flight Mgmt System (2)
DADC (2)	DADC (2)
EFIS (2)	EFIS (2)
Crash Position Indicator	Crash Position Indicator
Integrated Comm Mgmt Sys	Integrated Control System (2)
GPS (provisions Only)	GPS (2)
AIDS	AIDS
Engine Inst Sys	Thrust Mgmt System with Display
DABS	DABS
CAS Computer & Display	CAS Computer
	Multifunction Display
Caution & Warning System	Caution & Warning System
GPWS	Incorporated in FMS

TABLE I.2

DABS DOWNLINK DATA (SHEET 1 OF 2)

PARAMETER	DESTINATION/USE	WHEN TRANSMITTED
Altitude Echo (ALEC)	Cross Check Alt. Rpting	Each Surv. Interr.
Master Time	Synchronization	Initial Contact
A/C Position Est. with Variance	FMC - Cross Check A/C Navigation	
Comm. Freq. Assign.	Int. Comm. - Set Comm. Freq.	On Contact/Freq. Chng.
ATIS & Terminal Info.		
Flight Rules	Info. Display (ATIS)	Initial Contact/Prior to Final Approach
Ceiling	Info. Display (ATIS)	Initial Contact/Prior to Final Approach
Visibility	Info. Display (ATIS)	Initial Contact/Prior to Final Approach
Altimeter Setting	Info. Display (ATIS)	Initial Contact/Prior to Final Approach
Active Runway/Rnwy. Assign	Info. Display (ATIS)	Initial Contact/Prior to Final Approach
Runway Conditions	Info. Display (ATIS)	Initial Contact/Prior to Final Approach
Surface Winds (At Several Locations Including Rwy. Threshold)	ATIS & Shear Computation & Display	Initial Contact/Prior to & During Final Approach
Wind at Approach Alt.	Shear Comp. & Display	Prior to Final Approach
Wind Profile @ 3000 Ft. Intervals with Time of Data Collection	FMC (4-D NAV Planning)	Initial Contact - Entrances to Term Area, Start of Descent
RVR & Landing Rules in Effect	Info. Display	Initial Contact/At Start of Final Approach
Vortex Advisory	Info. Display	Prior to Final Approach
Windshear Description	Windshear Comp/Display	On Final Approach
MSAW Warning	EHSI Display	On Initial Contact
T.O. & Landing Clearance	Pilot Display	As Appropriate
Rwy. Turnoff Assignment	Info. Display	On Landing
Route Info./Control		
Route Assignment, Up to Seven Waypoints with T.O.A. for Each	FMC - Info. Display	On Initial Contact
Course Assignment (If Different from Star)	FMC, Pilot Display	On Contact
Metering Fix Time	FMC - Info. Display	On Initial Contact
Route Changes	FMC - Info. Display	As Needed or Req. by Pilot
Approach to T.O. or Approach to Final	FMC - Info. Display	Prior to Final or T.O.
Threshold Time		On Final Approach
Weather on Route	Info. Display	After Route is Established or Changed.
Visibility		
Clouds		
Wind at Each Waypoint or Each Leg		
Severe Weather	FMC - Pilot Display	As occurance, and Updated as Storms Move.
Location		
Extent		
Gradients		
Severity		
Special Hazards		

TABLE I.2

DABS DOWNLINK DATA (SHEET 2 OF 2)

PARAMETER	DESTINATION/USE	WHEN TRANSMITTED
Traffic & CDTI		
Expected Traffic in Flow	Info. Display	After Initial Contact or When Change Occurs
ID's	Info. Display	After Initial Contact or When Change Occurs
Landing Sequence	Info. Display	After initial Contact or When Change Occurs
Position of Each	CDTI	1/Scan /Aircraft
Altitude of Each	CDTI	1/Scan /Aircraft
Speed & Direction of Flight for Each	CDTI	1/Scan /Aircraft
Vertical Speed	CDTI	1/Scan /Aircraft
Roll Angle	CDTI	1/Scan /Aircraft
VFR Traffic	CDTI & Info. Display	1/Scan /Aircraft
Position	CDTI & Info. Display	1/Scan /Aircraft
Altitude	CDTI & Info. Display	1/Scan /Aircraft
Direction of Flight	CDTI & Info. Display	1/Scan /Aircraft
Intentions (If Known)	Info. Display	1/Aircraft
Projected Encounter Aircraft	Collision Avoidance Warning and Displc	On Occurence, then 1/SCAN
ID	Info. Display	On Occurence
Time to Encounter	CA Display & FMC	1/Scan
REL Direction	CA Display & FMC	1/Scan
REL Alt. Assigned	CA Display & FMC	1/Scan
Range to A/C	CA Display & FMC	1/Scan
Response Assign.	CA Display & FMC	1/Scan
Position, etc. (CDTI Info.) If Not Already Sent	CA Display & FMC	1/Scan
Conflict Alert	CA Display	On Occurence
Projected Best Action	Pilot EADI or EHSI or C A Display	As Determined
IPC		As Required by ATCS
Ground Speed or Airspeed	Pilot Display & FMC	As change is needed
Altitude	Pilot Display & FMC	As change is needed
Direction (Hdg. & Track)	Pilot Display & FMC	As change is needed
Next Leg on Release	Pilot Display & FMC	As change is needed
Airport Surface Display Information	Pilot Display, Info. Display	Prior to final approach or during final approach.
Taxi Instructions: Taxiway route, hold short, proceed, other aircraft direction, location, gate assignment	Pilot Display, Info. Display	During landing, during taxi as required.

will require two data reply words per scan (one comm B, 56 bit reply, and one comm D, 112 bit reply). The data transfer can also be handled by one extra length message comm D reply. See reference 3 for detailed descriptions of these formats. Since up to 16 replies at the same azimuth can be accommodated in one scan, this should provide more than adequate data transfer capability even though several aircraft are on the same azimuth radial from the DABS interrogator.

DABS Beacon Uplink Data

The uplink data from the DABS ground system has a wide variation in data rates, some data occurring only once or twice during the entire terminal phase while other data occurs once per scan as shown in Table I.3.

The maximum transfer of data would occur when CDTI data are being transmitted. If five aircraft are assumed to be in the immediate area, approximately 245 bits are required for transmission of this CDTI information to each aircraft. During any one scan, up to sixteen 80-bit ELM messages are available. This allows 1280 bits of information to be transmitted to each aircraft in a single dwell time. Thus 1035 bits are available for other data during each scan time.

The foregoing analysis is superficial and does not take into account the number of aircraft on any one azimuth beam of radar coverage. If we assume that three aircraft are at exactly the same azimuth, then 3 x 245 or 735 bits would be required, leaving 545 bits for other data. Since CDTI is the most data intensive use of the system, and since in some cases less than one update per aircraft per scan would suffice for CDTI (for traffic which does not present an immediate hazard), the available data rate seems adequate. Other techniques, such as only a partial data dump per scan for most non-threat traffic, or broadcast of delta values (changes in position or track or velocity since last scan), would result in fewer bits per aircraft being transmitted within a CDTI update. A third alternative which would reduce the

required data rate is the simultaneous broadcast of CDTI information to all aircraft on a given radar azimuth segment. This approach may not be possible under present formats, but could be worked out within the present system concept with the addition of one or two additional formats or special message instructions in the surveillance field.

TABLE I.3

DABS UPLINK DATA

PARAMETER	ORIGIN	DESTINATION	UPDATE RATE	WORD LENGTH	TYPE MESSAGE	REMARKS
Altitude	DADS	ATC Display, Conflict Computer	1/Scan	16 bit	Surveillance	
Identification	A/C Wiring	ATC Display, ATC Computer	1/Scan	24 bit	Surveillance	
Pilot Acknowledge	Pilot Action	ATC Display, ATC Computer	1/Scan	1 bit	Surveillance	
Sys. Status	BIT	Info. Display, ATC Computer	1/Scan	3 bit	Comm. B	
A/C Capability	A/C Wiring	Info. Display, ATC Computer	1/Initial Contact	7-10 bit	Comm. B	Includes RNAV 4-D NAV, CDTI BCAS notation
Baroset	Inst. Sys.	ATC Computer	4/Min.	9 bit	Comm. B	
Position	Flt. Mgmt. Sys.	ATC Cmptr., Conflict Computer	1/Scan	38 bit	Comm. B	
Airspeed	DADS	ATC, ATC Display	1/Scan	7 bit	Part of Comm. B	
Track	INS/FMC	Conflict Computer	1/Scan	7 bit	Part of Comm. B	
Heading	INS (IRS)	Conflict Computer	1/Scan	7 bit	Part of Comm. B	
Roll	IRS	Conflict Computer	1/Scan	6 bit	Part of Comm. B	
Wind	IRS/FMC	Windshear Cmptr., ATIS	1/Scan	10 bit	Part of Comm. B	
Flt. Plan Data	FMC	Info. Display, Traffic Sequence	1 (On Req.)	0-250 bit	ELM, Comm. D	Includes waypoints, ETO, and vertical profile for 4-D NAV
Route Change Request	Pilot Action	Info. Display	1/Request	0-250 bit	ELM, Comm. D	
Clearance Request	Pilot Action	Info. Display	1/Request	2 bit	Comm. B	
Trk. Change	FMC	Conflict Computer	1/Scan	9 bit	Comm. B	
Emerg. Declare	Pilot Action	Info. Display, Traffic Sequence, ATC Display	1/Request	5-10 bit	Surveillance	Includes description of emergency, aircraft, medical, etc.
IFR/VFR	Pilot Action	ATC Computer	1 Initial Contact	1 bit	Surveillance	
Climb Rate	DADS	Conflict Computer	1/Scan	10 bit	Comm. B	
Ground Speed	IRS	Conflict Computer ATIS	1/Scan	9 bit	Comm. B	
Unreported or Unusual Weather	Pilot Action	ATC Computer ATIS	1/Event	5-20 bit	Comm. B	As events occur.

Note: All Comm. B replies required on a once/scan basis could be condensed into one, two-segment ELM Comm. D reply or one Comm. B and one Comm. D reply.

Data Bus Comparisons

Four common types of serial digital data buses have been developed for aircraft use. Their principal characteristics are tabulated in Table I.4.

The ARINC 429 bus with its low speed of 12-14 Kbps provides a noise immune, relatively EMI-free system which has a sufficient data rate for most applications. No high speed circuits or special terminations at branches are necessary since impedance matching is unimportant at that speed.

The high speed ARINC bus, with a bit rate of 100 Kbps, provides ample data rate for the inertial reference system, flight management system and autoflight system. Although the high speed bus susceptible to impedance mismatch (termination resistors are required on long buses with several drops or at single receivers), the production or susceptibility to EMI is still low, and relatively slow circuit components can still be used. The tri-level RZ signal has a definite advantage here to provide immumity from bit dropping or introduction of false bits over a zero.

The ARINC 453 VHS bus has its data format and speed modeled after MIL-STD-1553, but retains the unidirectional flow (transmit-receive links), individual word address labels, and word length formats of ARINC 429, thus providing more consistent I/O programming in the software. It has, however, an increased bit rate of 1000 Kbps. Impedance match, stub length, and EMI concerns now become much more important, and fast circuits are needed since the information is obtained on the state transition, and the data must be clocked into a buffer prior to use.

TABLE I.4

DATA BUS CHARACTERISTICS

DATA BUS TYPE	BIT RATE (bps)	WORD LENGTH (BITS)	DIGITAL FORMAT	VOLTAGE LEVELS	ADDRESS METHOD	DATA TYPE	DATA FIELD LENGTH	DATA FLOW	REMARKS
ARINC 429 Low Speed	13K (Nom)	32	RZ Bi-Polar 40 us Nom. Bit Width	1 = +6V to +10V 0 = -6V to -10V Null = ±2.5V	Label 8 Bits	BNR BCD A/N	19 Bits Plus Sign	Uni-Directional	Single Xmitter Mult. Rec.
ARINC 429 High Speed	100K (Nom)	32	RZ Bi-Polar 5 us Bit Width	"	"	"	"	"	"
ARINC 453 VHS	1M	32 +3 Sync	Manchester Bi-Phase 100 ns	±10V P-P (Nom)	"	"	"	"	"
MIL-STD-1553B (Multiplex)	1M	20	Manchester Bi-Phase 100 ns	9V P-P (Nom)	Command/ Response	BNR BCD A/N	16 Bits	Bi-Directional	Requires 1 Command Word 1 Status Message Word Per Block of Data (32 Words Max.)

MIL-STD-1553B defines a command-response multiplex bus which operates at 1 Mbps. This is a bi-directional bus which means that each terminal must transmit and receive, and that each must contain enough processor intelligence to decode the command word, determine how many words are required or being sent, and respond when this sequence is complete. A bus controller (computer) is required to control bus operation, sequence and amount of data transmitted, and source and receptor of data. Terminal-to-terminal data may either be sent through the bus controller or directly to the other terminal, but if it is sent direct, two command and two response (status) words are required for each 32-word sequence.

The obvious advantage of the complex MIL-STD-1553B bus is that only one wire pair with terminal status at the proper locations can carry all inter-system data. This results in a decrease in wiring, less EMI problems, and fewer input-output ports per system.

Disadvantages of the 1553B include failure effects (a main bus break or short can disable a complete set of systems), and the fact that a change in the system complement may require a complete revision of bus controller software. Failure effects can be minimized by addition of redundant buses and terminals and use of spare capacity in one of the user system computers as a back-up bus controller. The penalty for this capability gain is increased complexity and weight.

In comparing the ARINC and 1553B bus concepts, note that an ARINC bus can have many receivers but only one transmitter. Therefore each device that originates data will give rise to one or more buses, so that several dozen separate buses will be required on an aircraft. (This characteristic will be illustrated in the next section in connection with the aircraft displays.) Also, data-originating equipment and especially data receivers must have enough I/O ports for the various buses. On the other hand, a 1553B bus will support a plurality of transmitters as well as receivers. (Each bus can support 32 receive/transmit terminals, and each terminal can be multiplexed as required.)

In summary, the ARINC concept is simpler since it requires no bus controller; each word bears its own address. Also, the concept allows a number of receivers with simple logic detectors to select the desired data from the bus without the use of a complex terminal unit. However, many separate ARINC buses are required on an aircraft. The 1553 bus concept is more complex, requiring a sophisticated bus controller, software, and receive/transmit terminals. One bus or pair of buses would suffice for most of the aircraft equipment. A change in the equipment complement would likely require hardware changes with ARINC buses, and software changes with 1553 buses.

Intra-Aircraft Data Requirements

Table I.5 lists the intra-aircraft flow of data and its origins and destinations. The various applicable ARINC specifications list the data update rates for the majority of this equipment; therefore these rates will not be repeated here. Examination of ARINC 429 and other ARINC specifications reveals that most applications can be accommodated by the low speed ARINC bus with very few needing the high speed ARINC version.

One of the most data intensive areas of the future will be the Electronic Display System, and it will be examined as a worst-case condition. For the purpose of this example, the Electronic Display System consists of one EFIS for the pilot and one EFIS for the co-pilot. Each EFIS consists of two displays, an electronic ADI (Attitude Director Indicator) and an electronic HSI (Horizontal Situation Indicator) which also displays the weather

TABLE I.5

INTRA-AIRCRAFT DATA FLOW

SYSTEM	DATA IN	ORIGIN	DATA OUT	DESTINATION	SIMULATOR BUS NEED
VHF Comm	Desired Freq.	Integrated Comm. Control	Freq Tuned	1. Integrated Comm. Control 2. Multifunction Display	Input/Output
HF Comm	Desired Freq.	Integrated Comm. Control	Freq Tuned	1. Integrated Comm. Control 2. Multifunction Display	Input/Output
SELCAL			Call Annunciation	Integrated Comm. Control	Output
Autoflight System	Attitude, Hdg. Air Data Steering Data	IRS DADC FMS MLS GPS	Status Failures Sys Warn	1. Multifunction Display 2. AIDS	Output Only
MLS			Doviation, Distance	Auto Flight Sys FMS	None
Laser IRS (ARINC 704)	Initial Pos. Air Data	FMC DADC	Present Pos. Attitude Heading Gnd Track Gnd Speed	FMS, DABS Autoflt Sys, EFIS, DABS FMS	Output to EFIS Only
Radar Altimeter			Altitude, Validity	FMS, EFIS, Autoflt System	Output to EFIS Only
Wx Radar	Tilt, Rng Attitude	Integrated Control IRS	Digitized Video	EFIS, Radar Ind(Option)	Input/Output
DADC			Air Data Validity	FMS EFIS IRS DABS Autoflt Sys Aids	Output to EFIS Only
FMS (ARINC 702)	Position Velocities, Validity Air Data Altitude Waypoints,etc. Approach Deviation Position Est., Alt., etc.	IRS, GPS DADC Radio Alt. Integrated Control Sys., DABS MLS DABS	Steering Data Steering Data Dev., Desired Flt Path, etc. Waypoint Data Nav Data, Etc. Initial Pos,Time Position, Flt Path, Speed,etc. Status	Autoflt Sys EFIS Multifunction Display GPS, IRS DABS AIDS	Input from Int. Cont. Sys. Output to EFIS & MFD
EFIS (ARINC 600)	Display Information (See Source System)	DADC FMS IRS MLS Autoflt Sys Radio Alt	Status	AIDS	Input
CAS Computer	Traffic Data A/C Velocity, Position, Planned Flt Path	DABS FMS IRS GPS	Conflict Alert, Avoidance Commands, Traffic Display Information	EFIS, Multifunction Display	Output
Multifunction Display	See Originating Systems		Status	AIDS	Input
DABS	See DABS Downlink Data		See DABS Uplink Data		None
GPS			Position (3 Axis) Velocity (3 Axis)	FMS, EFIS, DABS	Output to EFIS Only

radar and ground mapping information. Each EFIS is assumed to contain its own symbol generator and display processor. A typical interface between the Electronic Display System and the on-board equipment is shown in Table I.6. The numbers in column 5 indicate the number of buses required for each equipment function.

As can be seen from the figure, the majority of information can be handled using low speed buses in the ARINC scheme. However, four VHS buses are required to interface with the weather radars. Four buses are required for redundancy; there are two radars, each connected to both EFIS by separate buses. (This is because there are dual radars in the aircraft, and each radar is customarily interfaced separately with each EFIS for redundancy.)

The four ARINC 429 buses could be replaced by a single MIL-STD-1553B bus because the average 429 bus has a loading of 50% or less. However, since the bus must handle all systems, not just the display, a bit rate capacity of over 1 Mbps is required and a single 1553B bus would not be adequate for all the functions of the Electronic Display System.

An alternate display/control arrangement would eliminate the EFIS display processor and would generate the display commands in the flight management computer or in a general purpose processor, using the serial data bus for transmission of display format commands. This scheme would require additional study to determine exact bus requirements, but a cursory examination indicates that even a much higher rate than that provided by MIL-STD-1553B would be necessary. This comparison shows that advantage of using dis-

TABLE I.6

DISPLAY SYSTEM INTERFACE
ARINC 600

EQUIPMENT	DATA BUS TYPE - ARINC 429			
	13 Kbps Low Speed	100 Kbps High Speed	1000 Kbps Very High Speed	ARINC Spec.
EFIS Control Panel	2*			
Thrust Management Computer	1			703
Flight Management Computer		2		702
Flight Control Computer	3			701
Inertial Reference System		3		704
ILS	1			710
DME	2			709
VOR	2			711
Radio Altitude	1			707
Weather Radar (Dual)			4	708
DADC	2			706
MLS	1			727
TBD	1			
TOTAL	16	5	4	

Display Update Rate 80/Sec

*Number of buses required to interface the equipment with the display.

tributed processors for special applications instead of using the central processor approach.

Provisions for on-board handling of DABS data will now be discussed. The DABS uplink data rate is 1 Mbps. It is required then that the ARINC 453 VHS bus be used to transfer this information to a buffer interface in a processor prior to distribution to the various display and usage elements. Conversely, downlink data must be accumulated in a buffer and then transmitted at the 1-Mbps rate during the reply interval. This buffering function is handled by a display interface unit (IU) in the present generation of equipment. This display interface unit is connected to a single display unit. Since much of the buffered information may also be used by the FMC and the pilots' EFIS, it is envisioned that this buffering function could be incorporated into the collision avoidance computer. This arrangement would allow conflict information and surrounding traffic and warnings to be sent directly to the EFIS. Additionally, this arrangement has the provision for using a totally ground-based CAS, an air-based CAS or a mix, such as the trimode system. Changing from one system to another would require minor hardware changes and a re-programming of the CA computer and the EFIS display processor. Investigation of the method of display, data use, and resolution of the question of ground command versus pilot decision from display for the CA function will require experimental simulations under many circumstances and flight scenarios.

Adequacy of DABS for CDTI/CA

The data available per scan from DABS appears adequate for all proposed functions. However, the question arises, is the scan rate of the DABS beacon sufficient to provide time for appropriate action?

An aircraft flying at 407 kmph (220 Kts) will travel 453 meters (1486 ft) in the four second interval between scans. If the aircraft begins a 0.052 radian per second (2 minutes or 3 deg/sec) turn, he can turn 0.21 radians (12 deg) in the four second interval. This creates an area of uncertainty in his position due to possible maneuvers of +/- 94 meters (309 ft) cross track and 10 meters (32 ft) along track. Since the resolution of most navigation systems is +/- 183 meters (600 ft or 0.1" lat/long), a total error of over 274 meters (900 ft) would be present in the A/C position. In order to turn 274 meters (900 ft) at a 0.105 radian per second (1 minute or 6 deg/sec) rate, he must start turning 5.8 seconds prior to projected encounter, or 655 meters (2150 ft or 0.33 n. mi.) from the point of danger. In order to provide this much warning, the alert must be sent up to 4 seconds ahead or 1128 meters (3700 ft or approximately 0.67 n. mi.) distance. To assure any margin of safety, the collision alert and action determination must be taken when the two aircraft are over 3.7 kilometers (2 n. mi.) apart under worst conditions. If the final decision is made in the air by aircraft equipment, the decision can be made at 1.85 to 2.47 kilometer (1 to 1.33 n. mi.) separation. The margin of safety here is obvious, but an extremely detailed study must be made of the best predictive means of providing conflict alert and best

evasive action information.

The above analysis did not consider navigation or radar error, altimeter errors, failure to receive the message on one scan, turn capability of light aircraft, and other factors which could increase the warning time needed. Also, simultaneous resolution errors in latitude and longitude are not considered.

As another example, we assume that CDTI other-aircraft coordinates are sent relative to own-aircraft over a 37 kilometer (20 n. mi.) latitude-longitude range with 7 bits of resolution in each direction. In this case the resolution is 1852 x 20/128 or 289 meters (949 ft) in each direction. Considering both latitude and longitude resolutions together, the maximum uncertainty due to resolution limitations is 289 x $\sqrt{2}$ or 409 meters (1342 ft). The total uncertainty then is 409 + 94 meters or 503 meters (1652 ft) This value is even greater than the error of 274 meters (900 ft) in the previous example.

Simulator vs A/C Requirements

The data requirements for a simulator are quite different from the actual aircraft bus requirements since most of the data will reside in one or two large computers. For example, assume that the ground system/ATC function is resident in one computer, the airborne functions in another, the control display for the airborne system in a cockpit (flight station) simulator, and the ground station control/display in a ground station simulator. The division between actual and "simulated" (i.e., resident software in a computer) is shown in the "simulator bus" column of Table I.5.

One other set of buses needs to be added to this list, i.e., the DABS uplink bus from the ground computer to the airborne simulator computer and a DABS downlink bus from the airborne simulator to the ground system simulator. These buses should be implemented using the ARINC 453 VHS bus, whose 1 Mbps rate corresponds most closely to the data rate and format of the DABS beacon system. These buses will simulate the R.F. transmission link of the ATC/aircraft beacon system.

If both airborne and ground functions are to be housed in the same computer, this data link must be simulated entirely in software. This would include simulated interface, buffer storage and translation, and data correlation with other system data.

Fiber Optics Application

The use of fiber optics for either uni-directional broadcast type buses or multiplex use is now possible since transmitters, junctions (dividers), directional junction, receivers, and bi-directional transmitter-receivers are all available. These devices are capable of bit rates of 10 Mbps or higher. The usual arguments for use of fiber optics instead of wire buses are savings in weight and space, immunity to EMI, and the elimination of inter-system crosstalk through electrical wiring faults. Fiber optics weight and space advantages disappear when the size and weight of armored fiber optic cable, terminations, splices and junctions are examined. The principal consideration then becomes one of EMI immunity. For wire buses, EMI appears to be no problem for the two lower speed buses but can prove troublesome at 1 Mbps. Recommencation for fiber optic links would then be

restricted to the ARINC 453 VHS and MIL-STD-1553B bus applications. One particular problem for multiplex buses with multiple receivers is the division of light at the terminal "drops." Most dividers are 50% devices, which leaves the remaining light transmission on the "bus" too low after two or three junctions are encountered. Various ratios of light division have failed to solve this problem and the problem of transmission bi-directionally onto the bus from a terminal. The best solution at present is to demodulate with a receiver and re-transmit down the bus, and to use an electrical transmission to carry the information to and from the using system. This approach, however, negates the major reason for use of fiber optics - EMI prevention.

Simulators provide quite a different picture for fiber optics use. The airborne simulation computer, the flight station, and the ground station are usually separated by distances greater than those normally found in aircraft. For this reason, interference between signals and waveform degradation are two major problems in simulators. Fiber optics provide a means of reducing this interference.

Application of DABS Beacon Data

Although there are many questions still to be answered about the maximum capabilities and limitations of the DABS data link, it is apparent that many benefits are accrued through the availability of the data. The question remaining then is how much data are enough and how much should be used. The usage and quantity of

data are involved in the questions: "Where will the data be used?" and "How will the data be displayed?" The viewpoint of pilots and air controllers seems to vary according to occupation, while the rest of the community is spread between the two diverse viewpoints. This total question can only be resolved by adequate technical study, empirical evaluation through simulation, and finally, adequate in-flight testing.

The nagging question left by this and other studies is one which involves not only a technical solution but also the question of the adequacy of the human as a safety instrument to prevent mid-air collisions. Some have maintained that the pilot can do anything if he is given enough information. The question then arises, "Why is this cockpit so confounded cluttered?" "What is the pilot supposed to do with all this data?" These are crucial questions which remain unanswered.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from this brief overview of data bus and data link operation.

1. Intra-aircraft data bus requirements are well documented by ARINC and MIL-STD-1553B, and present no problem with data rates.

2. The available aircraft data buses can accommodate the DABS requirements with no particular problems.

3. The DABS downlink requirement will utilize only a small percent of the available data link capacity.

4. The DABS uplink data rate is more than adequate except possibly for two areas, CDTI and conflict resolution, which will present the highest and most safety critical loading on the system. Initial study indicates that even this load can be handled adequately, but additional work is needed to verify this conclusion.

5. Simulation of the data link and buses will primarily be a question of proper software development to include interface and data bus/link limitations and peculiarities.

6. Although fiber optics can be used on any data bus application discussed herein, any benefits derived from their use is questionable without a major breakthrough in input/output devices, in termination, and in multi-path splice (divider) technology.

Several recommendations can be made based on the study results and the indeterminate areas found during the study.

1. A study of conflict resolution/avoidance information requirements and display techniques should be undertaken. This study should include evaluation of several types of displays, the information required to make adequate resolution decisions, the desirability of redundant resolution decision elements (including the pilot), effect of the decision on surrounding traffic, and advisability of automatic decision/action elements or use of intermittent positive control (IPC) IPC for resolution.

2. The data time lag should be studied along with decision time effects of various error components to determine the amount of lead time needed between projected encounter, data transfer, resolution decision, action initiation, and successful resolution with acceptable safety margins.

3. The use of DABS data, both on the ground and in air, is an area which needs considerable simulation under various scenarios and display formats to determine the most effective use of the data available. It is of little use to transmit data that provides unusable information or an excess of information; both of these conditions degrade operator performance.

4. Since 4-D navigation and control is a goal of the 1990's ATC system, and the effect of a conflict resolution action may have a profound effect on such a system, a study is needed to determine the overall effects of conflict resolution and the best methods of minimizing any undesirable effects.

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II. LARGE-SCREEN COLOR CRT DISPLAYS
BY D. O. Noneaker

BACKGROUND

The impetus for this survey was the desire to provide a large-screen cathode ray tube (CRT) multi-function display in the aircraft cockpit to reduce the number of independent displays and thereby relieve some of the aircrew's scanning workload. This would represent a natural extension of the practice of utilizing small CRT displays which are essentially one-for-one replacements for conventional electromechanical flight instruments. The parameters of interest are the adequacy of pictorial presentation (resolution and readability), picture information refresh rate, demand placed upon the host computer, environmental considerations, ease of installation/integration, and cost.

This survey of display system and component vendors was intended to determine what equipment is now or will soon be available be on the market shortly to provide a large-screen CRT display for an aircraft cockpit simulator to be operated beginning in 1983, and used over a four to five year period. This will not allow for utilization of systems, components or techniques that are now in early research or preliminary development stages. In fact, all the vendors responding indicated that we are limited to their presently marketed product lines, with perhaps some minor improvement or variations. None indicated that anything significantly different was expected out of their labs and into production during the next several years.

This survey was not intended to define the technical parameters or design of the large-screen cockpit display, but in order to formulate inquiries directed toward the vendors, a display configuration was postulated. This "large-screen" is assumed to be a 48 cm (19-inch) diagonal tube with approximately 25 X 35 cm (11 X 15 inch) viewing area and is used to present primary instruments, alphanumeric data including warning, status, and check lists, and other indicator displays such as engine instruments. These various functions may appear simultaneously or selectively under control of a central computer or as manually commanded. Figure II.1 shows a conceptual view of such a display with an electronic attitude director indicator (EADI) positioned at the upper right, the electronic horizontal situation indicator (EHSI) in the lower right, checklists at the lower left, and a cdti display at the upper left. Significant requirements for this display include the windowing necessary to divide the screen into functionally independent areas, varying update rates for the different areas of the screen (high for the flight instrument displays, much lower for alphanumerics like checklists) colored areas for sky and earth, and the requirement for color and symbology standardization.

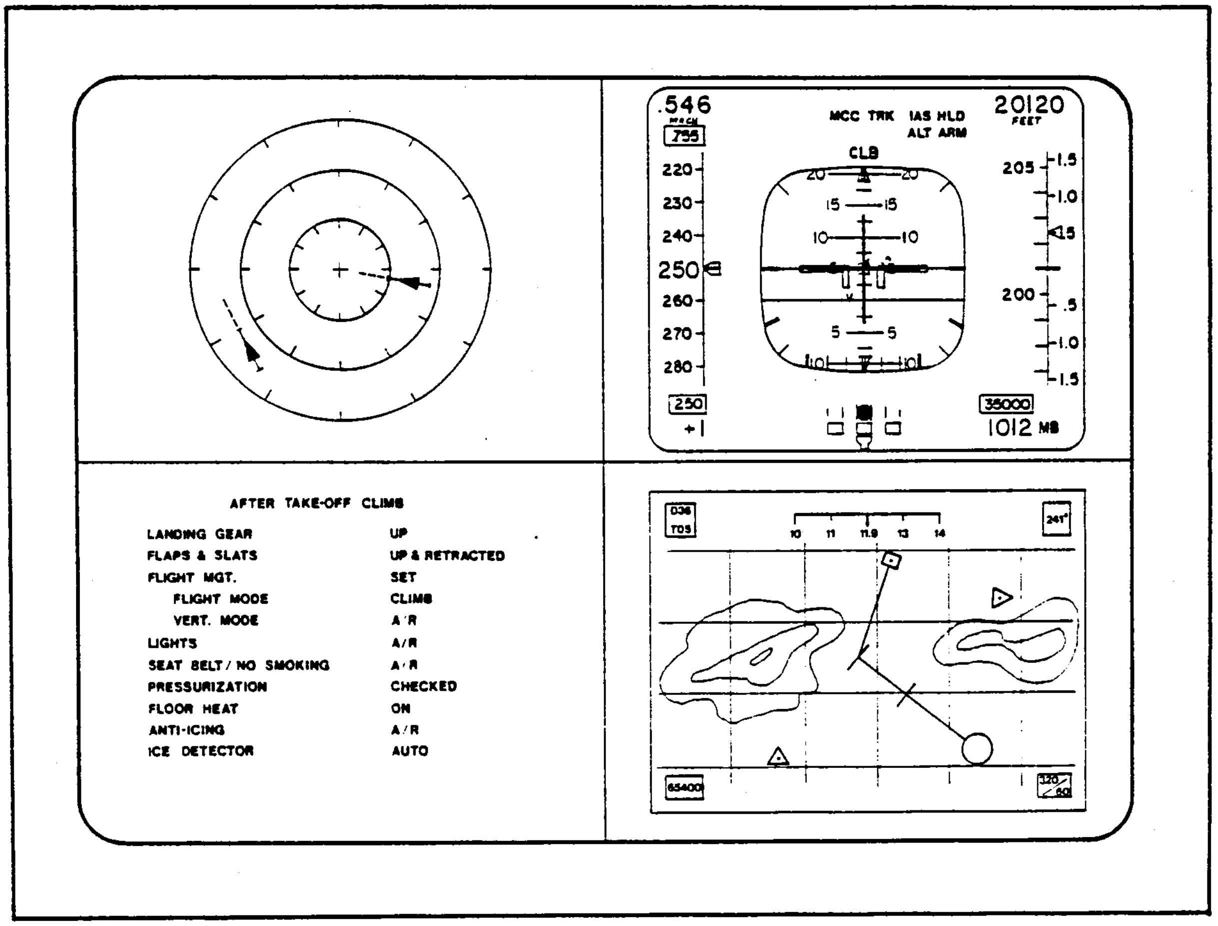


Figure II.1 - Conceptual Cockpit Display

TECHNICAL DISCUSSION

The survey of vendors reported herein is not exhaustive. The number of companies and laboratories engaged in some aspect of computer driven CRT displays is so large, and their interests so varied, as to preclude detailed discussions with each. Moreover, for proprietary or other reasons, some vendors contacted chose not to provide information. The approach was therefore to do a preliminary survey of industry directories, trade journals, and other literature. Representative vendors in the applicable subdivisions of the display field of interest to this study were then selected. This sample group was contacted to solicit information for this report. It is believed that the results represent a fair assessment of the state of the art in terms of available systems and components.

CRTs, Monitors and Display Systems

The cathode ray tube (CRT) is the display device in the display system. All currently available color display systems utilize shadow mask tubes, Trinitrons, or beam penetration tubes (voltage penetration tubes or penetrons). A short description of CRTs is found in Appendix C of this chapter. The CRT is designed either for magnetic (yoke) deflection or for electrostatic (plate) deflection. All full-color tubes utilized in the large-screen displays surveyed for this report are magnetic deflection types.

Monitors for raster-scan pictures are cathode ray tubes together with the necessary components and circuits to achieve a desired video display when supplied with primary power, video (picture) signal, and timing (synchronization) signals. These necessary components include dc power supplies to operate the CRT, electron

beam focusing mechanisms, electron beam deflection yoke or plates, deflection waveform generators, driver amplifier, and video (picture signal) amplifiers for electron beam modulation. Critical parameters for the monitor include the CRT spot size which affects the resolution, and the video amplifier bandwidth. The video bandwidth increases as the square of the resolution. It is a critical factor since the display cost varies with the bandwidth and hence on the square of the resolution.

Either raster-scan or stroke writing may be used for CRT display. In a raster-scan display, the picture is composed of a sequence of horizontal lines, as in a standard TV picture. In a stroke writing (or calligraphic or vector) monitor, the input signal includes the screen coordinates defining the end points of a line to be drawn on the screen, and monitor circuits must interpret these coordinates, generate waveforms to deflect the electron beam illuminate, the screen while moving the beam between defined coordinates at a controlled rate, and cut off the beam at the vector endpoint.

A major disadvantage of the raster-scan display is a stair-stepping appearance which is apparent when lines are nearly horizontal. This anomoly, due to the line structure, may possibly be mitigated by "anti-aliasing" techniques which are being explored at various graphics laboratories.

A stroke writing monitor can rapidly change lines on the screen. The old line is simply removed from the display list memory, and the altered line inserted in its place. In a raster-scan system in order to erase the old line, it must be redrawn in background

color and the new line inserted in refresh memory. The stroke writing monitor does not require the frame buffer memory which is a large cost item in a raster-scan system. The disadvantage of the stroke writer is that it is unsuitable for painting or coloring a large-screen area such as backgrounds, due to the selective writing overhead time.

Also, the stroke writing display can be built with higher resolution without excessive cost; its deflection circuitry cost is more or less directly proportional to resolution, while the cost of a raster-scan frame buffer increases as the square of the resolution.

A hybrid display is capable of both raster-scanning and stroke writing. The hybrid mode permits raster-scan presentation of slowly varying background, with rapid updating of specific lines or symbols. This latter mode is advantageous for flight instrument display, where only a small number of lines, symbols or cursors are changing rapidly, with only slowly altering background presentations.

Systems with combined raster-scan/stroke writing capability are available and used in small CRT displays today such as the Collins -- EFIS 700 system. However, for the large-screen display considered, such systems are not now available. As best as can be determined only one company, Evans and Sutherland, has any production capability in large-screen color CRT raster/stroke equipment, and this only in large image manipulation/animation systems not germane to this study.

For monitors using beam penetration CRTs, there is a further requirement on its circuits, since to change color requires a change in electron beam velocity and hence in beam acceleration (anode) voltage. This represents a significant high voltage switching requirement.

The monitor input signal format for a raster-scan presentation is dependent on the circuitry design within the monitor. It must be matched to the rest of the display system interfacing to the monitor. The video input to the monitor is usually either composite video similar to commercial TV video signals or three separate analog color signals (red, green, blue or RGB), each with a number of distinct levels depending upon the number of refresh memory bits assigned to each. The synchronization signal is an integral part of the single composite video waveform, but in the case of RGB inputs, may be a separate input, or impressed on one of the color signals (usually green).

The display system includes the monitor with its CRT, the display processor to reformat data which is input to the system from an external source into signals appropriate to the monitor, a monitor controller, memory in which the picture information is stored for picture refresh, and special hardware to perform transformations on picture data. The display system usually interfaces to a host computer. The configuration, or architecture, of representative systems is described in a later section.

Display Resolution and Color

Resolution obtainable on color CRTs varies with the type of construction. Most consumer TV tubes have resolution on the order of 500 X 500 points. This resolution has proved inadequate for many commercial color graphic applications and some display systems now utilize monitors with higher resolution tubes (and correspondingly higher frequency response monitor electronics). Aydin produces 48 cm (19") monitors with shadow mask tubes having dot triad spacing (pitch) of 0.29 to 0.31 mm yielding a 1640 X 1320 triad resolution. Their monitors using this tube produce up to 1024 X 1024 30 Hz interlaced or 1024 X 512 60 Hz repeat field formats, with 25 MHz video bandwidth. This represents about the best resolution obtained on a 48 cm (19") shadow mask delta gun tube, and at present one manufacturer, Mitsubishi, produces these tubes exclusively. Some vendors (ISC) utilize a fixed convergence, in-line tube, the Trinitron; which is essentially a consumer TV product but does provide good resolution for a smaller 33 cm (13" diagonal) display tube size utilized. Table II.1 compares the performance of several CRT monitors. The Aydin 8026 and Ramtek GM 859, or equivalent, appears to be desirable for this application.

High resolution graphics are obtainable on vector or stroke writing systems such as the Adage system or the Megatek 7000, both of which use the Kratos monitor with a high resolution beam penetration tube. Resolution is variously stated as 4000 X 4000, 20,000 vectors, or .006" (.15 mm) spacing. The beam penetration tube provides only 4 colors - red, orange, yellow, and green - made up of the two primary colors, red and green.

TABLE II.1

CRT MONITOR PERFORMANCE CHARACTERISTICS

Make	Display Resolution	Available Triads	Video Bandwidth	Horizontal Frequencies
Aydin 8025	615 X 715	1640 X 1320	15 MHz	15-18 KHz
Aydin 8026	1024 X 1024	1640 X 1320	25 MHz	28.3-34.6 KHz
Cromemco RGB-19	756 X 484	-	15 MHz	-
Chromatics 1999	512 X 512	-	-	-
Ramtek GM 859	1280 X 1024	-	40 MHz	-
Genisco GCT 3080	1024 X 1024	-	-	-

The resolution required for the cockpit display is governed by the most detailed and cluttered functions on the display, the electronic attitude director indicator (EADI) and electronic horizontal situation indicator (EHSI) displays. Collins (Rockwell) has concluded, in developing EADI and EHSI instruments for the Boeing/United 757 aircraft, that a resolution of 500 X 500 is necessary to show adequate details in the instrument display (reference 1). These same displays are contained in approximately the same scale on the large-screen display being addressed, and the linear dimension of each is approximately one half the screen dimension. Since from a practical standpoint resolution must be uniform across the display, 1000 X 1000 resolution is indicated for the large-screen, such as that attainable on the aforementioned Aydin monitors, or other monitors using the high resolution Mitsubishi shadow mask tube.

The functions other than EADI and EHSI that are to be displayed on the CRT consist of alphanumerical data, status indicators (typically vertical bar instrument format) and other video data which is significantly less critical in resolution than the flight instruments, and could be quite adequately presented on a medium resolution system, 500 X 500 or less resolution. The display would be smaller, less expensive, in terms not only of CRT and drive circuit complexity and frequency response, but in size and speed of data manipulation. The manufacturers of high resolution systems all produce middle-of-the-line systems with lower resolution and other capabilities, as do a number of vendors who are not in the high-end market. Some of these are mentioned in Appendix A. To summarize, the flight instrument presentation is the system functional element that requires the high end display system with increased complexity and cost.

The graphical symbology and colors for the EADI and EHSI have been subjects for discussion for some time by the avionics manufacturers and user agencies, principally the airlines. At present they seem reasonably firm and there will shortly be an approved ARINC Characteristic developed by the AEEC (reference 2). These are the standards being used by Collins to produce the United/Boeing EADI and EHSI. The most significant point is that blue is deemed a necessary color in the display, which eliminates consideration of beam penetration tube displays for this function, leaving only the shadow mask tube displays as acceptable for the system under consideration.

Display Form Factor and Electrical Characteristics

The selected CRT display must occupy prime panel space in the flight station, and must physically fit within the equipment space behind the panel. The envelope dimensions are therefore important. Likewise, weight and power dissipation are always significant considerations in flight station layout. Table II-2 summarizes these parameters for the same monitors previously discussed. A generalization of the data indicates that for the 48 cm (19") diagonal CRT under consideration, the form factor is approximtely a 51 cm (20") cube, weighing 45 kg (100 pounds), and dissipating approximately 250 watts. The frontal area (panel space) of 2580 square cm (400 square inches) and power of 250 watts is roughly comparable to the smaller CRTs being replaced.

The behind-the-panel extension of about 51 cm (20 inches) is somewhat more for the large CRT as is the weight. Not considered here is the additional drawer or rack containing display electronics, which may be located in less critical space. The monitor form factor is not expected to change significantly in the future. The form factor is determined by the CRT envelope dimensions. The tube body depth is fixed by the maximum practical deflection angle spread, which is about 1.75 radians (100 degrees), plus the length of the tube neck to accommodate the electron gun(s), focus electrodes, and deflection yoke or plates. A major decrease in depth is dependent upon development of the "flat CRT" technology (Appendix C), not now a viable alternative.

TABLE II.2

CRT MONITOR MECHANICAL/ELECTRICAL CHARACTERISTICS
(RACKMOUNT VERSION WHEN APPLICABLE)

Monitor	Diagonal Size (cm)	Exterior Dimensions (W x H x D cm)	Weight (Kg)	Power (W)
Aydin 8025/8026	48 (19 in)	48 x 44.5 x 50 (19 x 17.5 x 19.7 in)	45 (100 lb)	250
Cromemco RGB-19	48 (19 in)	48 x 43.0 x 54.6 (19 x 17 x 21.5 in)	45 (100 lb)	250
Chromatics 1999*	48 (19 in)	50 x 43.7 x 58 (19.7 x 17.2 x 20 in)	67 (150 lb)	600
Ramtek GM 859	48 (19 in)	48 x 44.5 x 50.8 (19 x 17.5 x 20 in)	45 (100 lb)	250

* Dimensions are of monitor only. Weight and power include computer drawer.

Since the initial utilization of the large-screen CRT will be in a simulator, the behind-the-panel extension is not critical for this application. However, looking ahead to operational use, the greater depth of large CRTs will be a significant disadvantage since the depth of the instruments is a design limitation on providing improved down-look visibility for the pilots.

It is generally conceded that the CRT display is only an interim solution to the cockpit display problem, and that the eventual solution will involve the use of flat panel displays--plasma, electroluminescent or other such technologies. Work on such devices is ongoing, and a usable product could possibly evolve to supplant the large-screen CRT by the time the system is to be installed in an aircraft. This would alleviate the form factor difficulties associated with depth of the CRT display.

Present progress in flat panel technology, however, does not indicate high probability of color high resolution panels being available within the decade of the 1980's. It is more probable that only monochromatic high resolution flat panels will be available for the next decade or two. Thus there will probably be a period from 1985 until about 1995 during which the cockpit designer must choose between a high resolution color CRT and a high resolution monochromatic flat panel display.

System Configuration

In order to present the multi-function display described a system architecture such as indicated in Figure II.2 is indicated. The aircraft systems interfaced are those which provide information to be displayed. These will include, normally, the Flight Director Computer, Area or Inertial Navigation Computer, Aircraft Master Warning System, Integrated Instrument Control System for engine and other instrument and status indications, and perhaps other peripherals such as keyboard manual display control panel. As configured in the example, such data would be processed by the pre-processors unit, acting as host computer, which would allocate the display area to have the desired graphic images appearing on screen for the programmed or commanded mode. The graphics hardware function represents character and vector generators, scroll, zoom and such functions achieved in hardware.

The resulting images are written into the replicated refresh dual port memories through direct memory access (DMA), and the monitor controller, under processor command, refreshes the display from

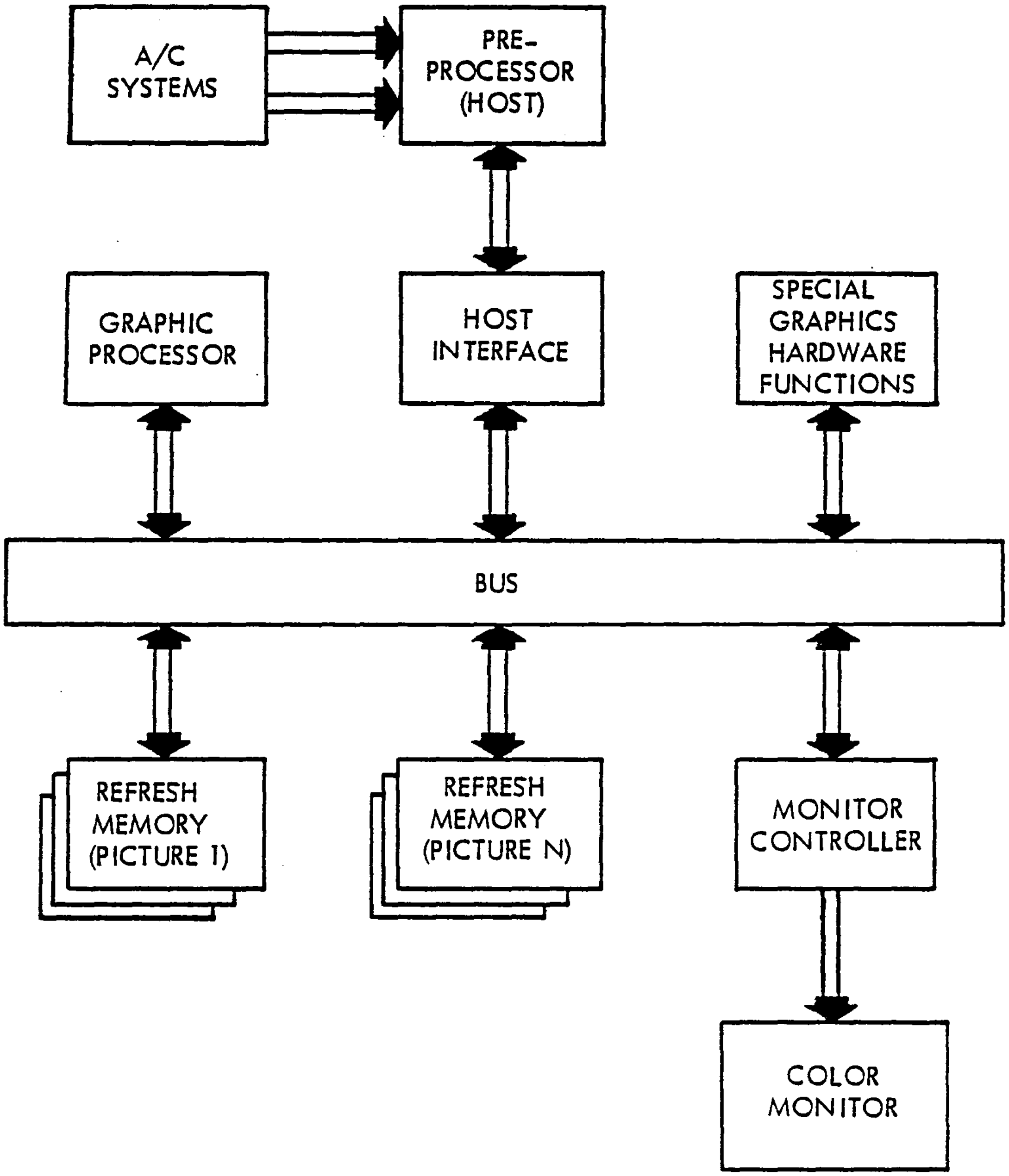


Figure II.2 - Conceptual System Configuration

these refresh memories. The multiple functions displayed can be obtained by windowing under processor control, refreshing different segments of the display from different refresh memories (channels).

A refresh memory consists of several memory planes of random access memory (RAM), each plane containing one bit for each resolution element (pixel) of the image. For the system being considered, a plane for a full screen display contains 1024 X 1024 bits, and a typical full color presentation utilizes 12 bits per pixel (4 bits or 16 intensity levels per color) so that a typical complete refresh memory has 12 planes of 1024 X 1024 RAM memory.

An alternative configuration, indicated in Figure II.3, is to produce the various images that are to be displayed in auxiliary memory, achieving windowing by loading segments of these images into a single refresh memory. Since some of the images consist of alphanumeric data which may not require full color representation, conservation of total memory may result.

The achievable rate of data change in the display depends upon the attainable DMA rate of the system. To obtain a measure of of desired rate, a 10 per second total update of the EADI full color presentation would require approximately 500 X 500 X 12 bits/pixel X 10 per second rate or about 30 megabits per second. Actually, the total image does not change this rapidly. Only picture elements which change need to be updated. The elements which are changing are horizon, pitch indices and roll indices.

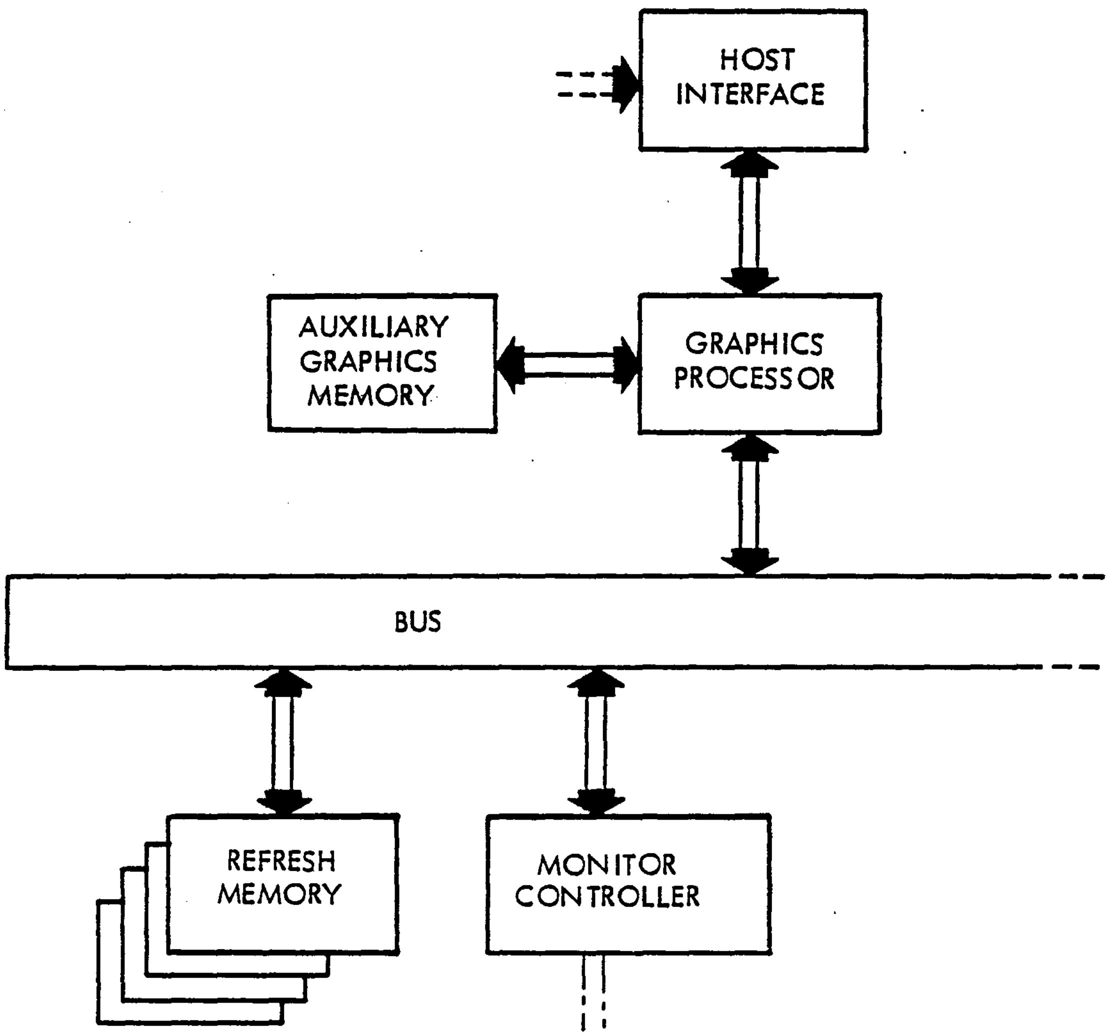


Figure II.3 – Alternate System Configuration

If these are contained in refresh planes which are prioritized, or treated as overlays, only these planes need be refreshed at the higher rate. Thirty megabits is then an unrealistic requirement. Ramtek quotes 26 megabits/sec as the maximum DMA rate for the 9400 system, so the desired picture refresh rates are achievable.

Of the display systems surveyed, some of which are described in Appendix A, five systems have been selected as meeting the requirements for this application. Again, since this survey is not exhaustive, this does not imply that other vendors do not have similar systems available. The five are:

- Aydin Controls 5216
- Ramtek 9400
- Genisco 3000
- Ikonas RDS-3000
- Smiths Industries PDG

These five systems are described and compared to the conceptual system just discussed.

The Aydin Model 5216 Display Computer is combined with a high resolution color monitor such as the Aydin 8026 to constitute a high performance system. The 5216 utilizes a dual bus architecture, system bus and memory bus, allowing simultaneous activity on each. This permits multiple processors in the system (Intel 16-bit 8086), which probably will allow it to perform the host computer function indicated in Figure II.2 as well as graphics processing. Dual-ported 1024 X 1024 X 16 frame buffer allows pixel loading of one million pixels per second without interrupting the refresh. Expansion memory of up to 512K words permit program storage, cache and scratch pad usage. Figure II.4 is a simplified block diagram of the system as it might be configured for this application.

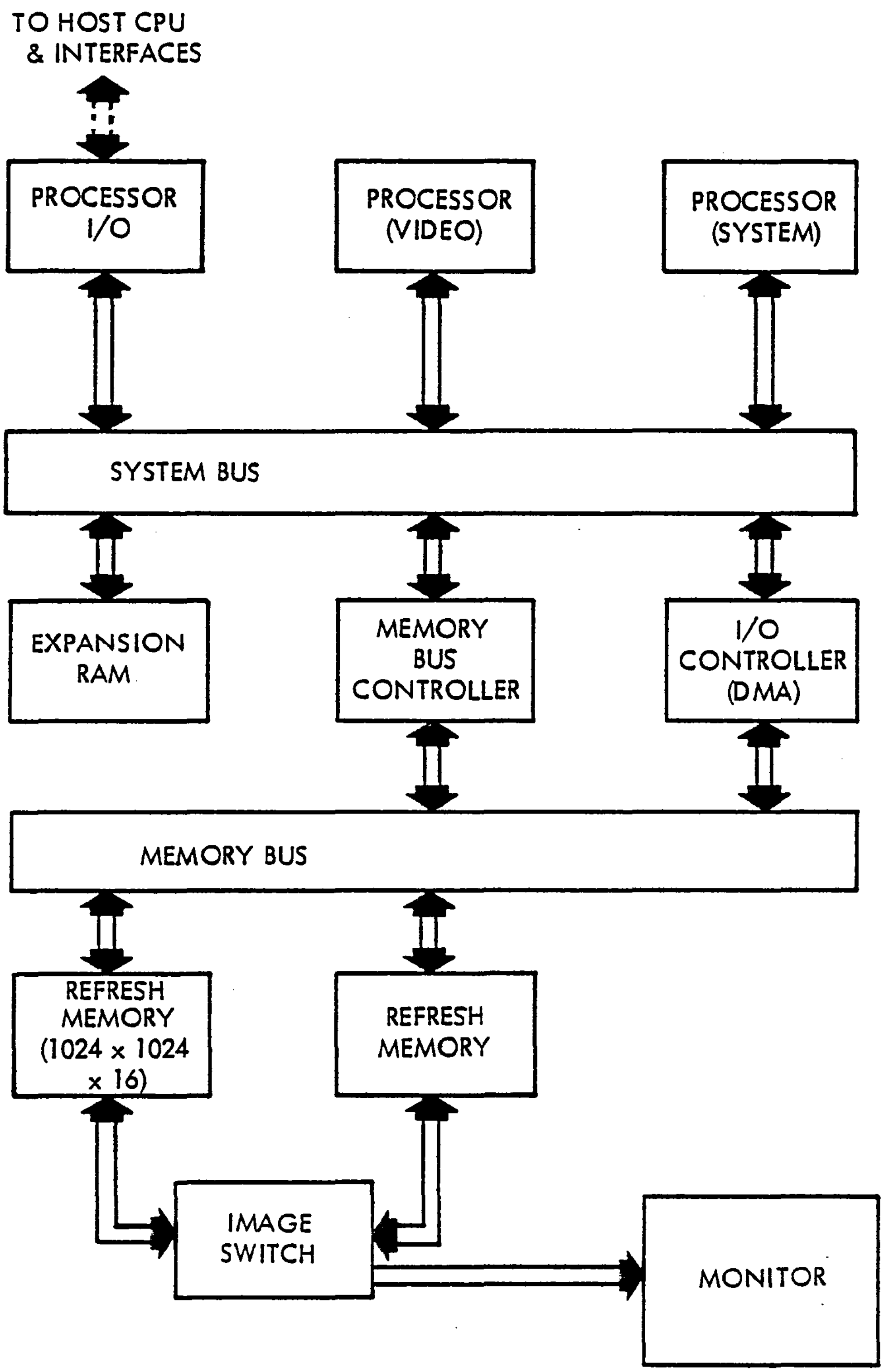


Figure II.4 - Aydin 5216 System Configuration

The Ramtek 9400 series display system also uses a dual-bus configuration to achieve simultaneous system and image activity. The system, with the high resolution Ramtek GM 859 monitor for example, has 1024 scan line by up to 1280 element resolution and up to 16 bits per element. The display processor uses a Z-80 microprocessor and memory maps of up to 512K bytes. A memory control processor, with a 16-bit bipolar special purpose micro, draws primitives into refresh memory and performs clipping, zoom, and pan. Processor memory expansion of up to 128K bytes is available. Figure II.5 shows the functional diagram for the system. The video generator provides the monitor drive signals and can perform overlay mixing and video lookup tables for color transformation. Extensive software packages are available to perform graphical functions which include 32K X 32K virtual picture and sub-pictures stored as graphic subroutines.

The Genisco 3000 series digital graphic display system, with a high resolution color monitor such as the Genisco GCT 3080 48 cm (19") 1024 X 1024 RGB monitor, also utilizes a dual bus architecture as shown in Figure II.6. The programmable graphic processor is a discrete 16-bit parallel processor, and can store and execute its own display-controlling programs, which can be passed from host via the CPU interface. It has DMA transfer rate of 1.67 million words/sec. The character/vector generator provides standard and special alphanumeric characters, and for drawing straight-line vectors at high speed. Character rotation and zoom with background and foreground control is provided.

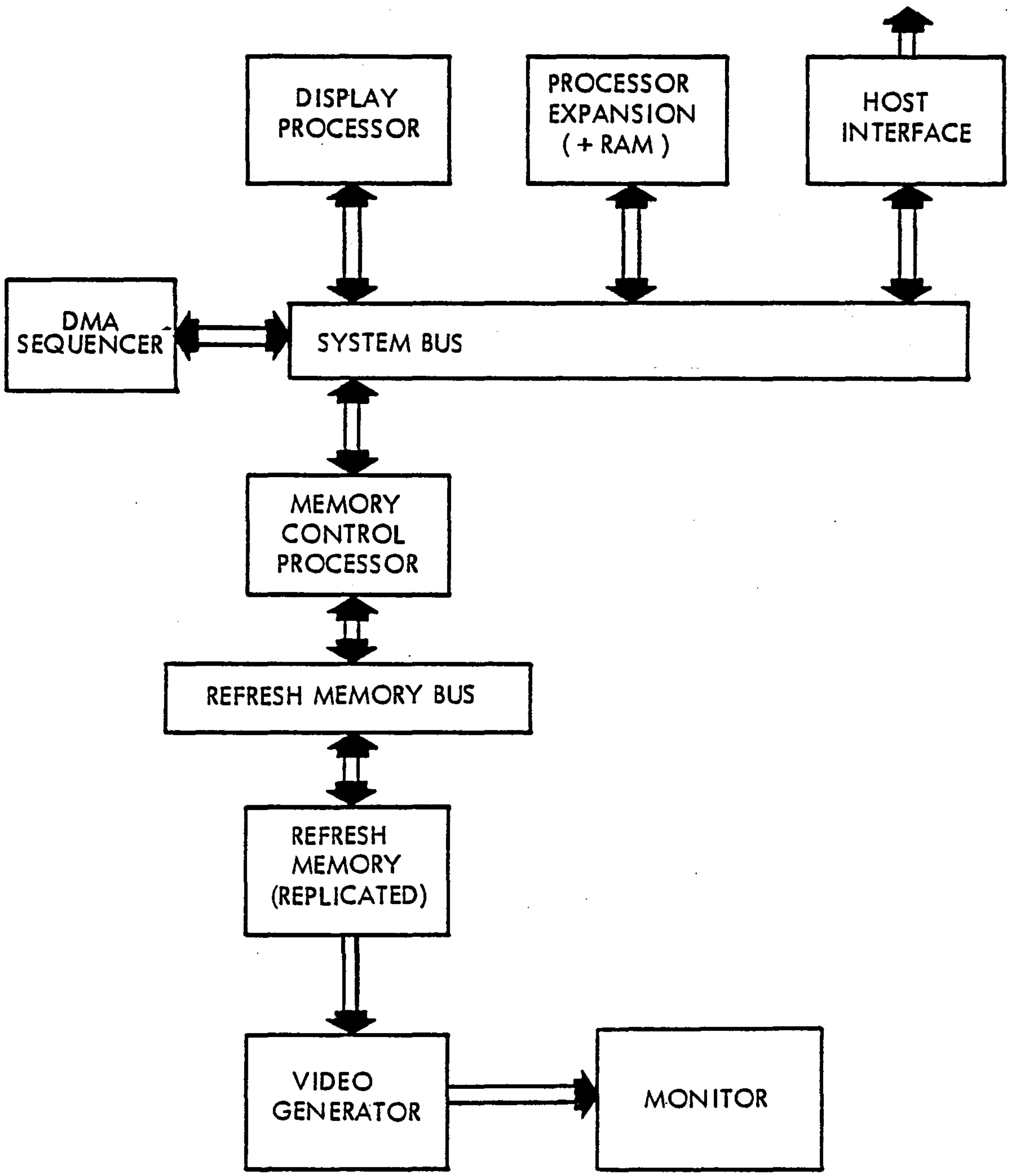


Figure II.5 - RAMTEK 9400 System Configuration

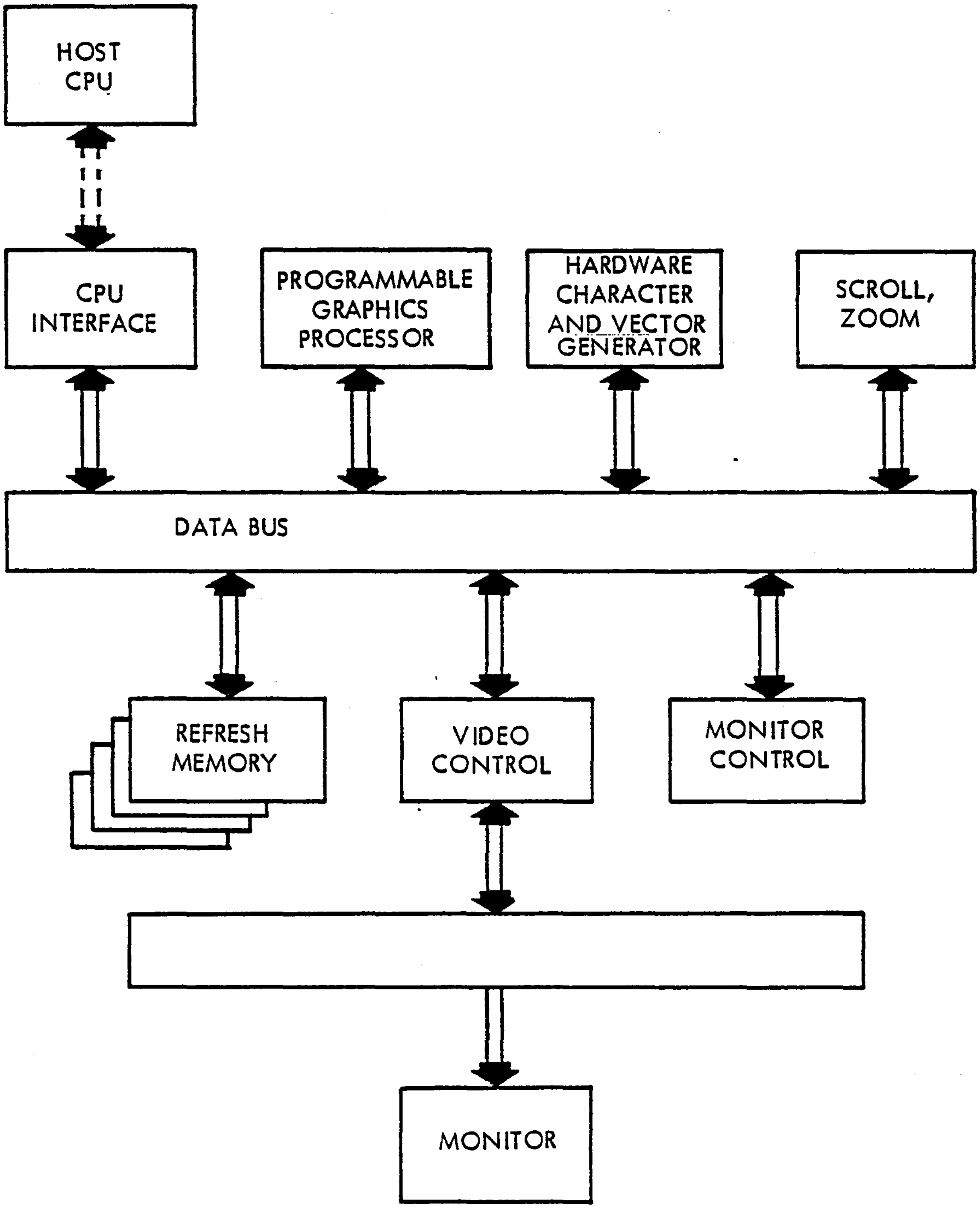


Figure II.6 - GENISCO 3000 System Configuration

The scroll/zoom module alters refresh memory plane addressing and timing to provide the effects. Refresh memories can be configured in as many planes as desired, in display size up to 1024 X 1024. The video control provides master timing and sync, while the monitor control connects the refresh memory planes data to appropriate composite video for the monitor(s).

The Ikonas RDS-3000 Raster Display System offers a high performance graphics system made up of modular components utilizing a multiple bus architecture with a main data bus which is 32 bits wide. With this architecture, traffic on the main bus is kept to a minimum and the other buses are optimized in width and protocol for the data being transmitted. The processor has a cycle time of 200 ns and is based on the AMD2903 bipolar bit-slice microprocessor. Graphics and image processing are enhanced by allowing the host computer direct access to the frame buffer, program memories, color look-up tables, and microcode store.

A single hardware multiplier allows 3-D transformations to be accomplished in 4 microseconds per point, or 6 microseconds per point when perspective is included. These hardware math boards may be paralleled for enhanced transformation times of less than one microsecond.

Other special hardware features include user-selectable raster characteristics, vectors, windowing, viewport, zoom, scroll, pan, and user-defined character generation. Future enhancements include hardware for high-speed fill. Up to four RGB ports may be included with reduced performance. Figure II.7 illustrates the Ikonas system architecture.

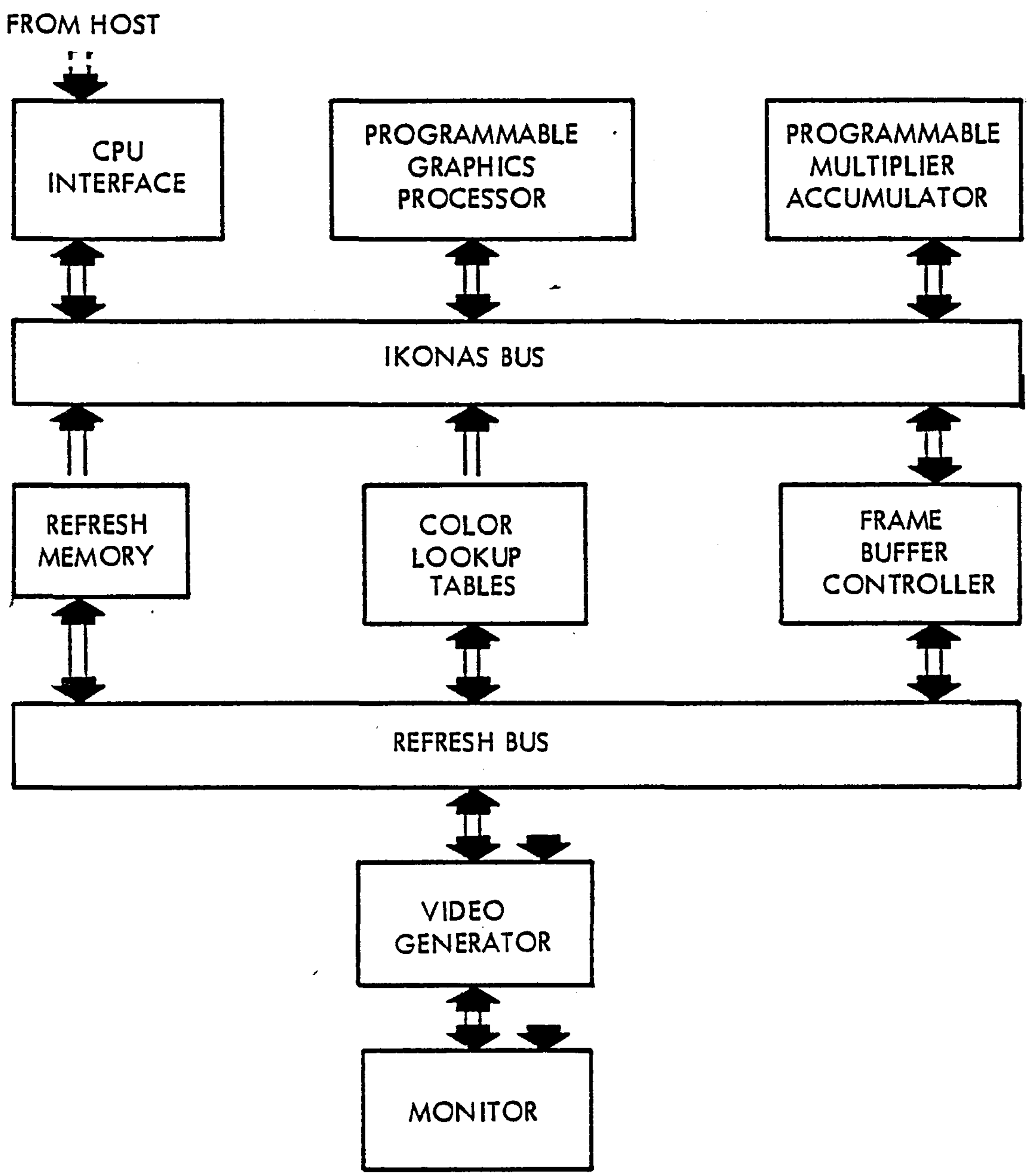


Figure II.7 Ikonas RDS-3000 System Configuration

The Smiths Industries PDG Programmable Display Generator is a versatile hybrid which combines calligraphics, television raster and arc (radar) raster capabilities into one unit. A number of different standard interface schemes are provided (RS-232C and a 16-bit parallel interface compatible with the PDP-11) and a 1-MHz MIL-STD-1553A bus interface is available as an option.

Math processing is handled by a 3-MHz AMD 9511 floating point chip. AMD lists maximum processing times for this device as follows:

16-bit integer multiple	64 microseconds
32-bit floating point multiple	56 microseconds
32-bit floating point cosine	1.63 microseconds

Raster resolution of the PDG is limited to 512 X 512 pixels, four bits deep. Other features included are all-digital vector generation, hardware conics, programmable symbols, a choice of penetration or shadow mask color, the use of a rho-theta stroke generation system, and a shade generator employing prioritized shade codes. Two independent output channels are available. The system architecture is illustrated in Figure II.8.

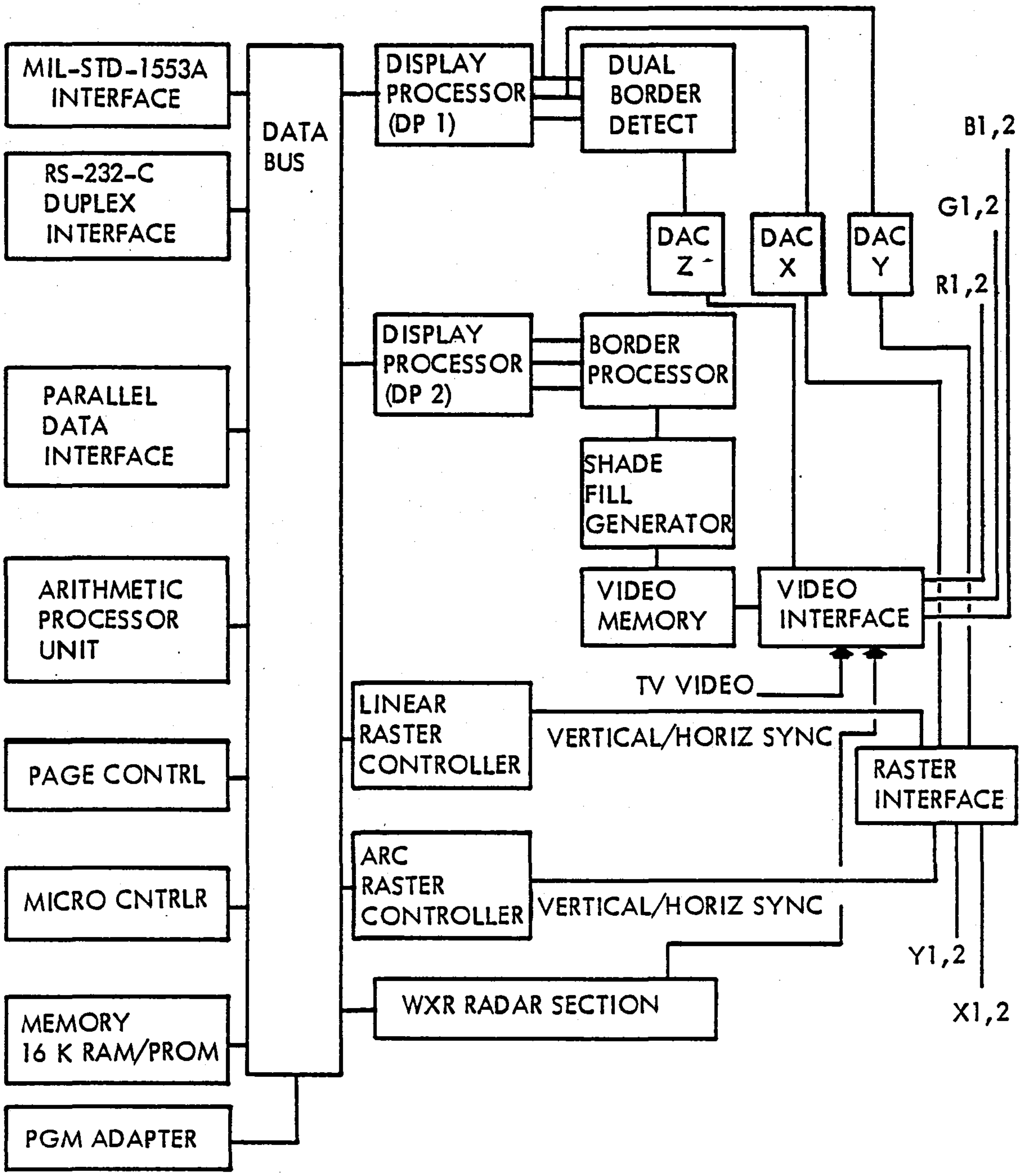


Figure II.8 Smiths Industries PDG System Configuration

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions arfe drawn from the results of this brief survey.

1. The only presently feasible choice for the large-screen full color display application is a high resoltuion (1000 X 1000) shadow mask cathode ray tube display, operating in raster-scan mode, with the display processor providing windowing of the display area to permit the desired multi-function simultaneous display.

2. Combined raster-scanning and vector line drawing is desirable for the electronic flight instrument application. However, this feature is not available in any suitable large-screen display even though it is provided in smaller color CRT displays. All large color CRT monitors are capable of raster-scan only.

3. The display system can be essentially configured for simulator purposes from present commercially available resources, with the exception of a vector line drawing capability. Some unnecessary features will be obtained in any available display system. True flight configuratioin will require special repackaging, and this will provide opportunity for some redesign, in order to tailor the system components to the specific application, with some resultant decrease in complexity.

4. Five systems which should be considered for use in a 1983 simulator are:
   - o Aydin Model 5216 Display Computer with the Aydin 8026 monitor.
   - o Ramtek 9400 Series Display System with the Ramtek GM 859 monitor.
   - o Genisco 3000 Series Digital Graphics System with the Genisco 3080 monitor.
   - o Ikonas RDS 3000 Series Graphics Processor and Raster Display Systems with Ramtek GM 859 monitor.
   - o Smiths Industries PDG Programmable Display Generator.

5. The environmental uncertainties, particularly the effect on tube convergence and focusing of in-flight shock and vibration using the shadow mask CRT, are still undetermined. Physical damage to tube structure by the flight environment is not regarded as a problem by the tube manufacturers and users.

6. The use of a beam penetration tube (penetron) display system avoids the resolution limitation of the shadow mask CRT. Penetrons have been proven in military flight hardware, but cannot now produce full-color displays. Development of full-color penetrons in the near future is judged to be unlikely by the display community, so penetrons are not applicable to to the full-color system addressed in this report.

7. For the large-screen display of formats such as an aircraft systems monitor and a checklist which are less demanding than electronic flight instruments, lower resolution systems

are adequate. Such systems are available from numerous vendors, including the five discussed in the body of the report and several others listed in Appendix A.

Recommendations for implementing the large-screen color CRT display in an advanced concepts flight station in 1983 are listed below:

1. Investigate the practicality of incorporating vector as well as well as raster-scanning in a commercially available large-screen color monitor.

2. Develop a set of requirements for the large-screen color display system based on a preliminary allocation of functions to each display and best estimates of various formats which should be explored. Based on this set of requirements, determine if any of the commercially available display systems have adequate display processors.

3. If none of the commercially available systems have suitable display processors, determine the practicality of modifications or enhancements to obtain the required capability.

4. Proceed with the procurement or development of a large-screen color display system based on the outcomes of the above recommendations.

APPENDIX II.A

DISPLAY SYSTEM VENDORS

1. ADAGE,INC.

Adage produces a graphics system that uses the Kratos CRT monitor. This operates as a 4-color stroKe writeing beam penetration tube. Resolution is quoted as 23000 vectors on a 0.5 mm (0.006") spacing - quoting the low end of the Kratos specification. Three versions of the system are produced, identical up to the computer interface. One is stand-alone, using an ADAGE minicomputer, one has an interface to SEL, DEC, or DG mini-computers, and one is configured as a direct replacement for the IBM 3350 terminal.

The system uses a 56 bit control word, hardware multiply and divide, with zoom, 2D/3D, and other options. Configured to minimize host computer loading for graphics functions.

System price is about $40,000 for the low end 4100 to about 00 $80,000 for the 4145.

2. AYDIN CONTROLS, INC.

Aydin produces a variety of graphical equipment including display computers and generators, color monitors and high resolution full graphics display systems.

The 5216 display computer system utilizes an Intel 8086 16-bit microprocessor with 1024 X 1024 X 16 bit refresh memory capacity and red-green-blue (RGB) outputs at 16 levels each.

Features include:

- Vector and circle generator
- Direct memory access
- Roll, scroll, zoom
- Mass storage controller
- Dual-ported frame buffer
- Software support packages
- Color monitors - Ayden Models 8024, 8025, 8026

System price of the basic 5216 is from $10,000 to $80,000.

The AYDIN 8295 high resolution system is a monochrome calligraphic (stroke writing) system which can produce random line drawing with a resolution of 1024 X 1280.

3. <u>CHROMATICS, INC.</u>

The Model 1999 is representative of the available color graphic computers. This system has a video display with 48 cm (19") diagonal raster-scan color CRT (3-gun shadow mask) with 26 X 36.8 cm (10.25" X 14.5") display area, 512 X 512 addressable dot resolution, and A60 Hz field rate. Nine sector convergence controls are provided. Eight foreground and eight background colors are provided. The tube is from Mitsubishi.

The CPU is a Z-80, and refresh memory is 130K bytes of dynamic RAM. Program memory has 6K bytes of EPROM and 1K bytes of RAM. Display functions include:

- graphic and alphanumeric modes
- cursor
- four windows

Serial interface is provided, and options include expansion of program memory and floppy disk, vector generator fill and graphics package, and parallel interfaces.

System price is $11,000 plus options.

4. CROMEMCO, INC.

Cromemco is primarily a computer manufacturer selling micro-computer systems with CRT terminal graphic interfaces which fit into the computer, and an RGB monitor.

The SDI Color Graphics Interface for the Cromemco computer has 756 X 484 pixel resolution using 48K display memory, providing 16 colors or shades of gray.

The RGB-19 color monitor uses a 48 cm (19") delta gun shadow mask CRT, and 15 MHz video.

System price is $7,000.

5. GENESCO COMPUTERS, INC.

The GCT 3000 modular graphic display system generates raster-scan, pixel oriented display data. Capbility is widely variable with module solution.

The upper end features:

- up to 1024 X 1024 color pixels (256 colors)
- interfaces to most host minicomputers
- 48 cm (19") high resolution RGB monitor
- character/vector generation
- scroll, zoom

DMA

controls over 32 refresh memory planes

extensive software support.

The system price for a high resolution system with eight memory planes for about $50,000.

6. GRINNELL SYSTEMS CORPORATION

The GMR 27 and GMR 37 graphic television display and imaging systems are modular designs and can be configured over a wide range of capability. The GMR 27 is the lower capability, flower price system. It has capability for 1024 X 1024 element resolution and generates RS-170 compatible video.

The GMR 37 has 16-bit parallel TTL bidirectional computer interface, up to 1024 X 1024 element resolution, up to 16 colors, blink, memory plane overlay, and alphanumeric and vector graphics.

System price is not known

7. IKONAS GRAPHICS SYSTEMS, INC.

Ikonas builds high performance modular hardware for raster scan computer graphics.

Features include:

frame buffer, 512 X 512 up to 32 bits/pixel or
1024 X 1024 up to 8 bits/pixel

32-bit Ikonas processors

vector generator

matrix multiplier

color look-up table

light host loading (e. g., PDP-11)

RGB monitor - Aydin 8025

run-length encode buffer available for animation.

The price for a typical system - 512 X 512 X 8 -32 bit processor, 4 matrix multipliers, high resolution monitor is $56,500.

8. INTELLIGENT SYSTEMS CORPORATION (ISC)

ISC manufactures stand-alone color graphics terminals/ computers. Typical of the product line is the 3800 series which features:

33 cm diagonal CRT, 80 dot (31.5 dot triads per cm) (80 per inch) with (0.32 mm pitch).

Trinitron tube

built-in mini-disk

Z80 processor

optional math chip

I/O with DMA controller

8 foreground, 8 background colors

character generator

software support systems.

System price is $10,000.

9. MEGATEK CORPORATION

The Megatek Whizzard 7000 refresh vector graphics system provides constant intensity sharp vectors with 12 bit, 4096 X 4096 resolution. It draws over 20,000 short vectors. Other features are:

optional 2D/3D transformations
vector generator
rotation, scaling, translating, scrolling, zoom
separate viewing areas/viewpoints.

The 7000 uses a Kratos monitor with "4-color" beam penetration tube.

Price with 3-D transformation hardware and beam penetration tube is $53,000.

10. NORPAK, INC.

Norpak's VDP (visual data processor) is a computer graphics processor, capable of full color at 1024 X 1280 resolution, with zoom, scroll, real time digitizing, and output to raster color monitor or to beam penetration for monochrome vector graphics.

11. RAMTEK CORPORATION

Ramtek builds a series of graphic display systems and monitors. The 9000 series display systems produces raster-scan output video from refresh memory to provide up to 12 bits per pixel at 512 X 640 resolution. An optional graphics

generator provides end point vectors, conics and other features. It interfaces to most common minicomputers to permit high speed 16 bit parallel data transfers.

The 9400 series is the top of the line. It generates up to 16 bits per pixel with 1024 X 1280 resolution. All the features of the 9000 series are available, plus a selection of specialized video generators. Sub-pictures, 32K X 32K virtual pictures, translation, rotation and scaling, pan, zoom, blink, color/intensity translation, graphic primitives, line texture, windowing and declutter are all available under program control.

Price for maximum system is $87,000.

12. THREE RIVERS COMPUTER CORPORATION

The CVD/2 color video display is a moderately priced color raster display system featuring run length encoding and 640 X 480 point resolution, with RGB RS-170 525 line video. The system is a peripheral to a PDP-11 minicomputer, with an option to interface to the Texas Instruments TILine.

The CVD/2 features double display buffer system, color palette and character generator. Options include cursor, and memory expansion to 64K words and writable cursor overlay memory.

Price for a typical system is $16,000, less monitor.

APPENDIX II.B

CATHODE RAY TUBE AND MONITOR VENDORS

1. AYDIN CONTROLS, INC.

Among the graphical display equipment produced by Aydin are two raster-scan color monitors which are representative of the higher quality monitors available in the industry.

The Model 8025 is a 48 cm (19") diagonal color monitor with composite and RGB inputs, horizontal frequency range of 15 KHz to 18 KHz with typical line rates of 525 lines, ranging to 585 lines, with 30-Hz frame rate and 2:1 interlacing. Ten screen area convergence controls are provided. Upper video frequency is 15 MHz. Size for rack-mounting is approximately 48 cm wide by 45.7 cm high by 50.8 cm deep (19" x 18" x 20").

The model 8026 is physically similar but designed for 1024 X 1024 30 Hz interlaced or 1024 X 512 , 60 Hz repeat fields, with 25 MHz video bandwidth and horizontal frequency of 28.3 KHz to 34.6 KHz.

Both use fine pitch shadow-mask CRT with .29 mm dot triad spacing. Effective display area is 38.7 cm X 27.9 cm (15.25" X 11"). Resolution is 1640 vertical X 1320 horizontal available triads, or 900 TV lines for the 8025, 1000 TV lines for the 8026.

2. CONRAC CORPORATION

The Model 5411 monitor has a 40 cm (16") shadow mask CRT, and RGB input with 800 TV lines resolution. It has 80 alphanumeric lines.

The rack-mounted version 5411RS90 is $4,700.

3. DUMONT (Thompson (CSF)

Dumont builds beam penetration tubes, 48 cm (19") and 53.3 cm (21") rectangular, "4-color". They operate 9 to 18 KV anode with P-49 phosphor or their new E-26 phosphor for high brightness and resolution.

One of their tubes is used in the Loral equipment for S3A retrofit. It is now undergoing a program of environmental testing.

4. KRATOS, INC.

The Los Altos Kratos division, formerly Display Systems, Inc. builds monitors only. Their beam penetration stroke writers (2 color) use 53.3 cm (21") and 63.5 cm (25") tubes from Dumont (Thompson CSF) and Thomas. These are used on Adage and Megatek systems. They also build a 63.5 cm (25") full color raster-scan monitor for flight simulators.

The Pasadena division has built small penetron tubes, but is not in the large-screen business.

5. RAYTHEON COMPANY

Raytheon builds beam penetration tubes up to 50.8 cm (20") round and 58.4 cm (23") rectangular size, flight hardened. These are high resolution devices ("super spot size") with split mode to reduce driver capacity by factor of four, 50% better resolution on red, and no refocus on color.

6. RAMTEK CORPORATION

The Ramtek GM 859 Color Monitor features 1280 X 1024 addressability on a black matrix high resolution CRT with 0.31 mm triad pitch (shadowmask) and 48 cm (19") diagonal screen. It accepts RGB video with a nominal 40 MHz video bandwidth. The rack version weighs 45 kg (100 lbs) and has a form factor 48 cm W X 45.7 cm H X 50.8 cm D (19" W X 18" H X 20" D).

APPENDIX II.C

COLOR CRTS IN BRIEF

The three-gun shadow mask color cathode ray tube has a screen made with a mosaic of phosphor dots. Rows of color dots are arranged such that the red, blue and green phosphor dots form a triangle (dot triad). Immediately behind the screen a metal sheet called a shadow mask contains one hole for each three-dot triangle. Three electron guns are arranged in the neck of the tube so that for a given deflection, the three beams will converge at a specific hole in the shadow mask, and diverge so that the beam from each of the guns will strike and excite one color dot, and by modulating the individual gun emissions, the phosphor color excitation is controlled.

The achievable picture resolution is limited by the spacing (pitch) of the dot triad/shadow mask hole combination. As the density of holes increases (increased resolution), the aiming of the beams (convergence) and alignment of holes and phosphor dots increases in complexity. Misalignment due to movement of the shadow mask in vibration environment and possible detachment in shock is a concern in flight usage. Another disadvantange of the shadow mask tube is reduced brightness due to mask interception.

Another full color CRT in use is the Trinitron. This tube utilizes a mosaic of vertical phosphor stripes instead of a mosaic of phosphor dot triads. The beam sweep is synchronized such that the beam is turned on only as it sweeps over the desired color phosphor stripe. This tube is

characterized by comparatively good color purity and high brightness at the expense of stringent beam switching requirements.

The penetron or beam penetration CRT is typically a single gun device which operates without an intervening screen. The tube phosphor is a combination of red and green phosphors, originally arranged in separate layers separated by a barrier layer. By modulating the gun anode voltage, and hence the electron beam velocity and energy, the layers could be selectively excited to provide color control. This technology has been developed by the evolution of solid state fast switching high voltage supplies for CRT anode modulation, and replacement of layered phosphors by coated phosphor particles. Green phosphor particles with a red outer layer, or green particle coated with inert material mixed with uncoated red particles are used so that low voltage beams excite the red but do not penetrate the green, producing red light, while high voltage beams penetrate to and excite the green, which can obscure the red. Intermediate values produce mixtures of the two primary colors. These tubes are usually referred to as "4 color" devices, for the red, orange, yellow, and green produced with increasing beam voltage.

The penetron avoids the resolution, convergence and vibration problems of the shadow mask CRT, at the expense of difficulties in high voltage switching control. Some of this difficulty has been reduced by the introduction of a control electrode (post anode) located near the screen of the tube, where the color (velocity) modulation is introduced with appreciably lower driving capacitance resulting.

The lack of a full-color capability (no blue component) is the primary limitation of the beam penetration tubes. To remedy this lack of full color is a goal of research at present, but this is still a distant achievement, if it is possible at all.

Shallow depth ("flat") color CRTs have been built using both the technologies discussed, with digitally addressed area cathodes producing multiple beams. Poor picture quality, cost, and complexity of the devices have limited their utilization, and they are presently classified as research laboratory devices.

APPENDIX II.D
VENDOR DATA

Adage, Inc.
One Fortune Drive
Billerica, MA 01821
(617)667-7070

Aydin Controls, Inc.
414 Commerce Drive
Fort Washington, PA 19034
(215)542-7800

Chromatics, Inc.
3923 Oakcliff Industrial Court
Atlanta, GA 30340
(404)447-8797

Conrac Corporation
Controls Group
3G Land Mark Square
Stamford, CT 06901
(203)348-2100

Cromemco, Inc.
280 Bernardo Ave.
Mountain View, CA 94040
(415)964-7400

Dumont Electron Tubes & Devices Corporation
750 Bloomfield Ave.
Clifton, NJ 07015
(201)773-2000

Genisco Computers, Inc.
A Division of Genisco Technology Corporation
3545 Cadillac Ave.
Costa Mesa, CA 92626
(714)556-4916

Grinnell Systems Corporation
2159 Bering Drive
San Jose, CA 95131
(408)263-9920

Ikonas Graphics Systems, Inc.
403 Glenwood Ave.
Raleigh, NC 27603
(919)833-5401

Intelligent Systems Corporation
Intecolor Drive
225 Technology Park/Atlanta
Norcross, GA 30092
(404)449-5961

III. SOFTWARE-CONTROLLABLE TOUCH PANELS
by L. Walthour

BACKGROUND

The transport aircraft of the 1990's will use a number of systems not found on today's aircraft, including MLS, 4-D Nav. CDTI, and DABS. While these systems improve efficiency and safety, they add additional display and control requirements to the flight deck. Furthermore, if a two-man crew is used, displays and controls which were formerly on the flight engineer's panel must be within reach of the pilots. Even today's flight station is crowded, and all instruments and controls cannot be located within optimum view and reach.

Progress is being made in consolidating and integrating the flight deck instrumentation using CRT displays. As a further step toward cockpit integration, attention is now being directed to improve the control or input function, and software-controllable touch panels (including CRTs) show promise for this purpose.

Software-controllable touch panels could not merely substitute for existing pushbuttons, switches, and keys, but could be central elements in the integrated cockpit. By careful functional design, many of today's tedious input functions will be replaced by the selection of pre-programmed options, and the touch panel is ideal for this purpose. One of the most important benefits that can be derived from a programmable panel is the ability to display only the most pertinent parameters. All necessary or irrelevant data can be removed from the panel sur-

TECHNICAL DISCUSSION

Touch Panel Applications

There are several rather distinct control/display applications for which touch panels may be suitable: basic option selection, decision-tree option selection, paging, data entry, and location selection. A touch panel of general utility would be suitable for all these applications. However, certain panels may be better suited for certain applications. It should be noted that the capabilities of a touch panel may depend as much on the software as on the hardware. Several application areas for touch panels are discussed below.

Basic Option Selection - This requirement is the ability to select one of a limited number of options which can all be displayed at the same time. The displayed options may be shown in either a one-dimensional or two-dimensional arrangement; that is, the options can be shown in a single line or they can be shown in a row-and-column array.

Decision Tree - The pilot may need to select an option from a list which is too long to be displayed on a screen at one time. If the options fit into a hierarchical or tree structure, a decision-tree approach may be used as shown in Figure III.1. This approach is particularly applicable to the multifunction display. In practice, the pilot must first select a particular mode of action, such as Mode 1 (see Figure III.2). This selection enables him to proceed to the second-highest level (VHF, HF, UHF, etc.). The process continues until the required action is performed or an accept or reject command is executed.

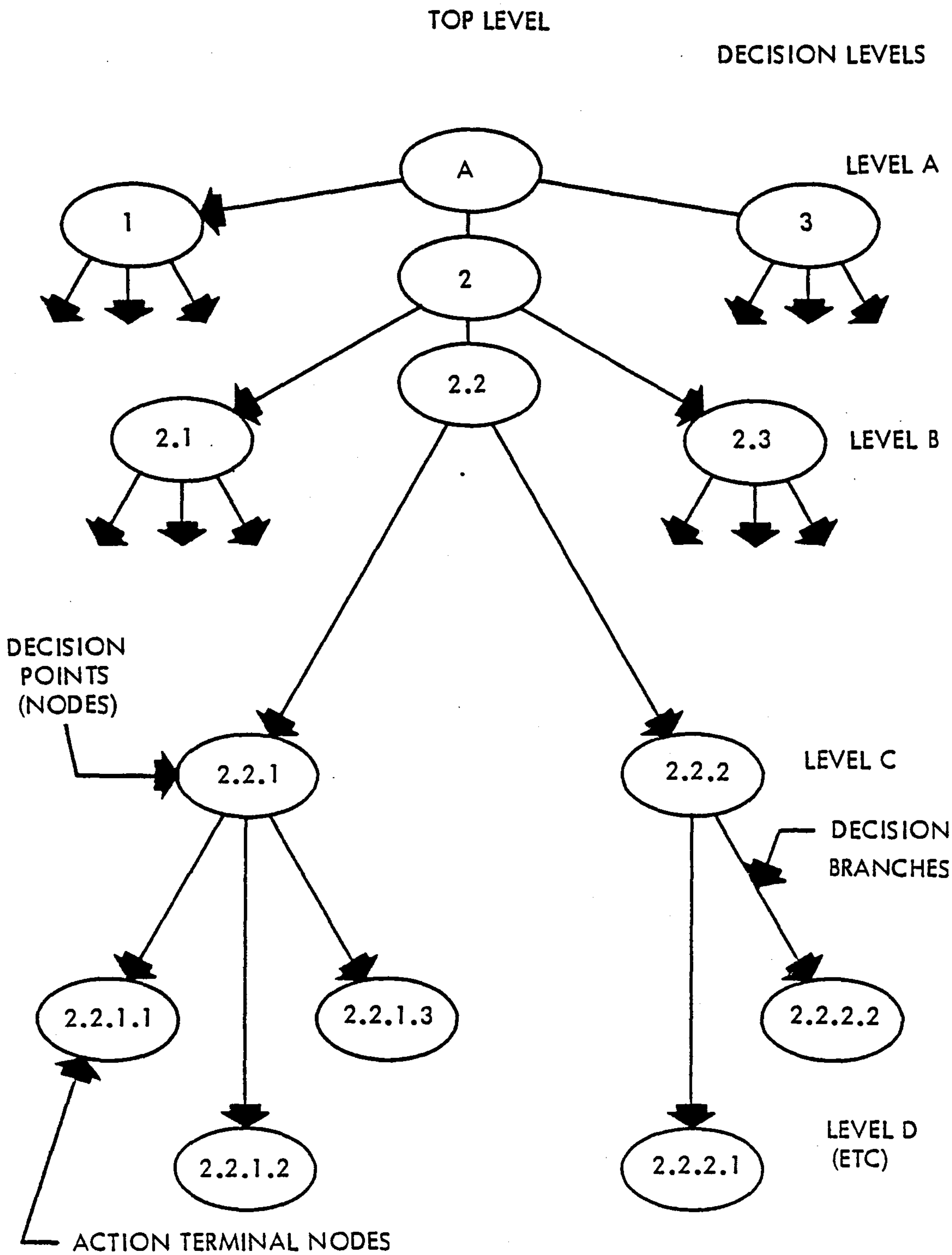


Figure III.1 - Decision Tree

MODE 1	MODE 2	MODE 3
COMMUNICATIONS (1st decision level) VHF-AM (2nd decision level) VHF-FM HF UHF-1 Channel No. 1 (3rd decision level) Channel No. 2 Channel No. 3 UHF-2	NAVIGATION TACAN INS Vertical Navigation Course Waypoint 1 Waypoint 2 Etc.	SYSTEMS INFORMATION Fuel Electrical Hydraulic Engine Etc.

Figure III.2 - Hierarchical Selection

The pilot should also have the ability to return to the previous input level from a subordinate level or to return to the top level of the tree.

Another method of option selection is based on a selection of options which are ranked in priority order (reference 9). A list of the highest priority options for a given situation are shown on the display surface. This "tailored logic" mode of operation is said to result in performance which is superior to that of standard touch panel logic.

If the pilot desires to select an option which is not shown on the priority listing, he could call for the next lower set of options. Alternately, the software could be designed so that the touch panel reverts to a conventional decision tree mode.

Paging - Occasionally a very long list of data items must be examined which do not fit into a hierarchical structure, as is the case during pre-flight checkout. This long list of data items may be divided into smaller, more manageable lists, called pages. A pilot should be able to manually or automatically step through a set of data pages by means of page advance, backpaging, and return to page zero controls.

Data Entry - Various schemes for entering alphanumeric data can be implemented with a programmable touch panel. The use of this operation can be minimized by clever use of option selection.

Position Location - When using a map display on the EHSI, it will occasionally be necessary to place a new waypoint on the map, for example, to navigate around a storm center. This may be done with a touch panel by merely touching the desired location. Software methods have been developed for moving a selected point by small increments. This use of the touch panel will help avoid the need for entering location data by keyboard.

Objects on a block diagram can also be selected by touch panel position location. A multifunction subsystem display may show, for example, the electrical diagram of the aircraft in skeleton form. If the engineer/pilot desires more detail about one section, he touches that section to call for a more detailed and magnified diagram. He could even actuate circuit breakers by touching their symbols on the electrical diagram. Research has even been done at M.I.T. on turning "knobs" which appear on CRT diagrams.

Basic Elements of the Touch Panel

From the general point of view, a touch panel consists of two basic elements: the display surface for displaying the various options, and the touch locator for detecting and locating the point on the display which is touched. The display surface may be a CRT, a flat panel, or any other surface on which options can be displayed under software control. The touch locator may be of a type which requires an actual touch, or it may be actuated merely by the presence of the finger. The use of these devices in a system is shown in Figure III.3 and several types of display surfaces and touch locators are listed in Figure III.4.

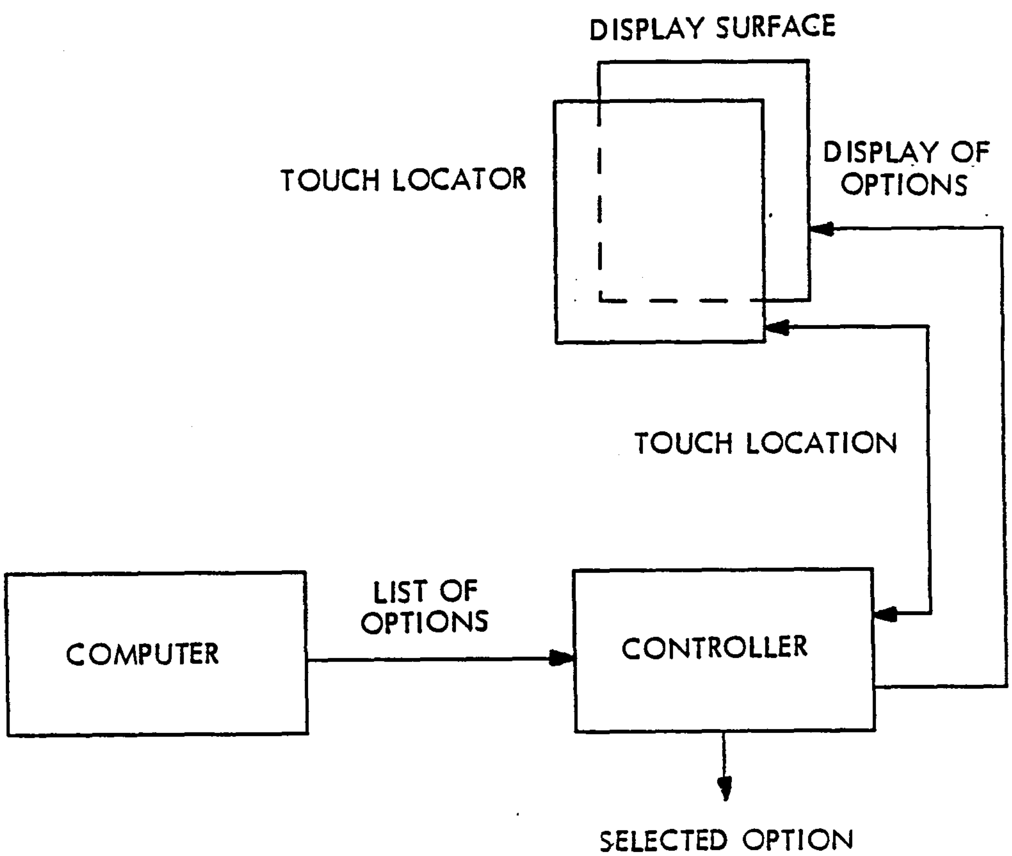


Figure III.3 - Touch Panel Basic Elements

DISPLAY SURFACE TYPES	TOUCH LOCATOR TYPES
1. CATHODE RAY TUBE	1. TOUCH-ACTUATED PANEL
2. FLAT PANEL DISPLAY	A. CROSSWIRE OVERLAY
A. ELECTROLUMINESCENT PANEL	B. VOLTAGE GRADIENT SUBSTRATE
B. LIGHT-EMITTING DIODE PANEL	C. CAPACITIVE COUPLING
C. LIQUID CRYSTAL DISPLAY PANEL	D. ECHO RANGING OVERLAY
	2. BEAM INTERRUPTION PANEL
	3. SIDE-SWITCHES FOR LINE SELECTION
	4. INDIVIDUAL MINI-DISPLAYS/SWITCHES
	5. DISPLAY WITH CURSOR CONTROL

Figure III.4 - Touch Panel Display Surfaces and Touch Locators

This generalized approach is taken to emphasize the potential types of touch panels which may be developed by combining various display and touch location concepts. Even though only certain combinations are available today, advances in a concept or manufacturing technology may lead to a new preferred implementation of the touch panel in the future.

Examples of touch panel types which are now commercially available or under advanced development, and their advantages and disadvantages, are shown in Figure III.5. Figure III.6 lists the names of vendors and the state of availability of representative touch panels.

TYPE	ADVANTAGES	DISADVANTAGES
Crosswire	Simple concept, basically digital, requires pressure for actuation, negligible light attenuation.	May produce parallax, limited resolution, reliability not proven,
Voltage Gradient	High analog resolution, curved CRT parallax minimized, requires pressure for actuation.	Requires A/D, other circuitry, attenuates light.
Capacitive Membrane	Negligible light attenuation, solid state technology.	Temperature susceptability, limited resolution, operates at slight touch.
Echo Ranging	High resolution possible, no light attenuation.	Requires periodic cleaning, damaged by scratches, limited temperature range, parallax due to CRT glass.
Beam Interruption	Solid state digital technology, MIL-SPEC versions available, widely used, no light attenuation.	Operates without touching, limited resolution, produces parallax, extra panel space required.
Side Switches	Simple in concept and use, high current capacity, good tactile feel, MIL-SPEC versions available, widely used, no light attenuation.	Switches subject to wear, limited selection, fixed 1-dimen. selection format, extra panel space required.
Mini-Displays/ Switches	Simple in concept, excessive depth not needed.	Complex interface, reliability not proven, fixed 2-dimen. selection format.
Rear Projection Switches	MIL-SPEC versions available, simple concept, widely used, good tactile feel, simple concept & interface.	Not suitable for high ambient light, fixed selection options, switches subject to wear.
Cursor Control	Can be used with HUD or other projection displays	Requires joystick or equiv. and pushbutton, requires positioning time.

Figure III.5 - Relative Merits of Touch Locator Types

TOUCH PANEL TYPE	SUPPLIERS	AVAILABILITY
Crosswire Overlay	Massachusetts Institute of Technology Solid State Technology Stanford Linear Accelerator Center	Laboratory Development
Voltage Gradient Substrate	Elographic Sierracin/Sylmar N/P Company	Commercial
Capacitive Membrane Panels	Industrial Electronic Engineers, Inc. N/P Company	Commercial and MIL-SPEC available
Echo Ranging Overlay	TSD Display Product	Commercial
Beam Interruption	Carroll Manufacturing Magnavox General Digital Corporation Control Data Corporation	Commercial and MIL-SPEC available
Side Switches	Interstate Electronics Corporation Maxi-Switch Company Clare Division General Instrument Corporation Licon Division, Illinois Tool Works, Inc.	Commercial and MIL-SPEC available
Mini-Displays/ Switches *	Industrial Electronic Engineers, Inc. ILC Data Device Corporation Boeing Technology Services Bormar Instrument Corp.	Commercial Laboratory Development
Rear Projection Multi-Legend Switches	Industrial Electronic Engineers, Inc.	Commercial and MIL-SPEC available
Cursor Control	Any of the Touch Panel types listed above may be used.	Requires touch panel and pushbutton

See Appendix A for a complete listing of Supplier names and addresses.

*This type includes multifunction keyboards, which consist of a plurality of mini-displays/switches.

Figure III.6 - Touch Panel Suppliers and Availability

Descriptions of Touch Panel Concepts

This section describes the various touch locator concepts which are listed in Figure III.5; in general, either a CRT or a flat panel display could be used with each of the touch location methods which are discussed.

These descriptions are generic in nature and do not represent specific pieces of hardware. Specific touch panels are described in Appendix B.

Crosswire Detection - The crosswire overlay touch locator shown in Figure III.7 consists of vertically and horizontally spaced wires under tension forming a square matrix array. Typically, the wires are mounted approximately 9.5 mm (3/8 inch) apart. The vertical set of wires is separated from the horizontal set by a thick plastic sheet with holes at the crossovers.

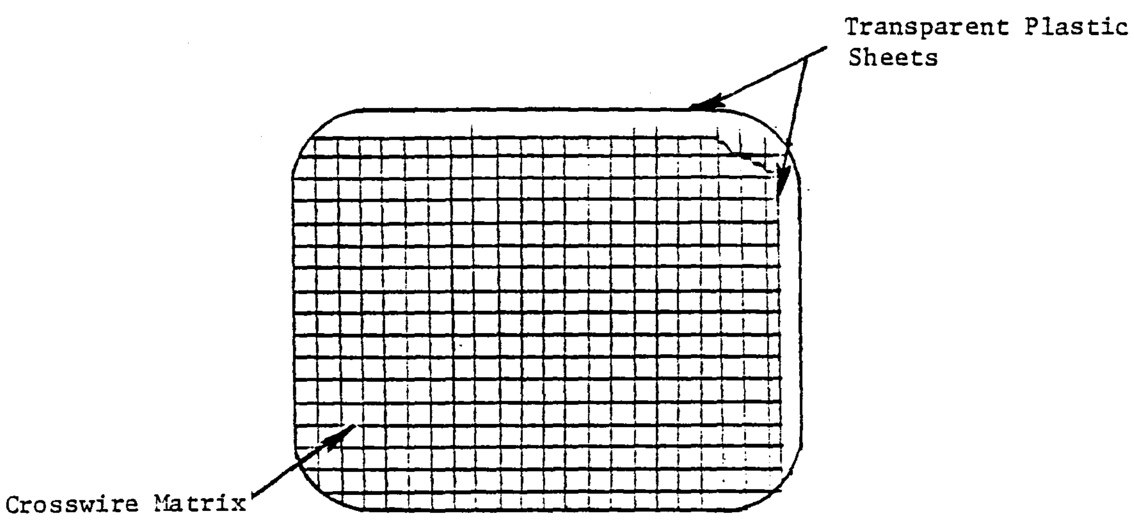


Figure III.7 - Crosswire Overlay

The entire matrix of crossed wires is enclosed between two plastic sheets which may be sealed to form an enclosed environment for the wires. When a finger presses against the outer sheet at a crossover, the outer sheet is deformed so that the outer sheet is pressed against the inner wire, making contact. Appropriate circuitry generates a digital output.

Voltage Gradient Detection - A typical sensitive position sensor shown in Figure III.8 consists of a curved glass sheet coated with a transparent resistive substrate and a plastic cover sheet backed by a transparent conductive layer. Finger pressure causes contact between the conductive layer and the substrate. The conductive layer functions as a voltage probe for obtaining the corresponding X and Y coordinates from the substrate, and the voltages or ratios are digitized by an associated circuit board for transmission to the host processor. Resolution of 0.1 mm (0.003 inch) can be achieved by this technique.

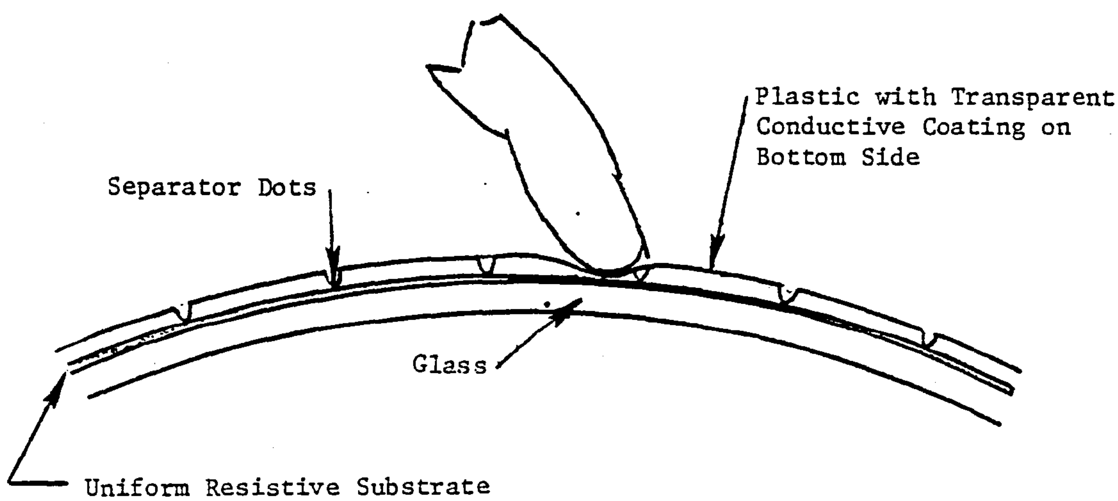


Figure III.8 - Voltage Gradient Detection

Capacitive Detector - The capacitive switch panel shown in Figure III.9 consists of a capacitive switch pad formed by applying a conductive surface A to the front of a rigid dielectric material. Two other conductive surfaces B and C are placed directly in line with surface A but on the opposite sides of A. Surface A forms the common plate between two capacitors A-B and A-C connected in series. The touch switch is part of a circuit carrying a low-voltage signal. Applying finger pressure to surface A reduces the amplitude of the signal because of additional body capacitance. The change in capacitance is sensed by the control circuit and the appropriate switching function is performed.

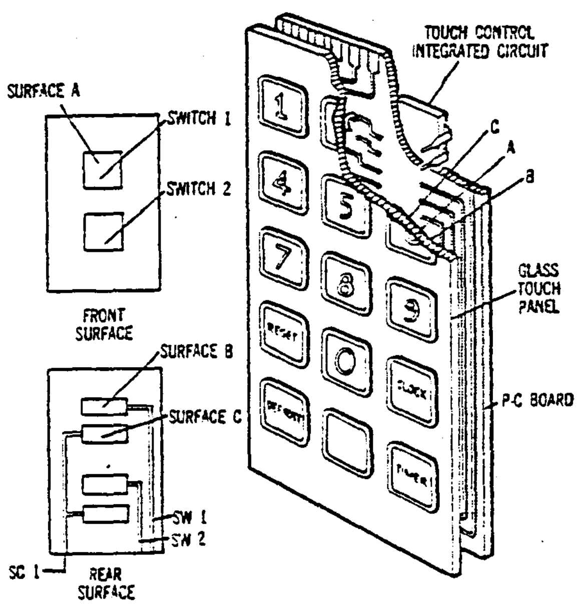


Figure III.9 - Capacitive Switch Panel

Integrated Control Panel - The Avionics Technology Research Branch at NASA-LaRC and the Naval Air Development Center are jointly sponsoring the development by the General Electric Company of an integrated control panel (ICP) similar to that shown in Figure III.10. One prototype for each sponsoring agency will be delivered by the summer of 1981.

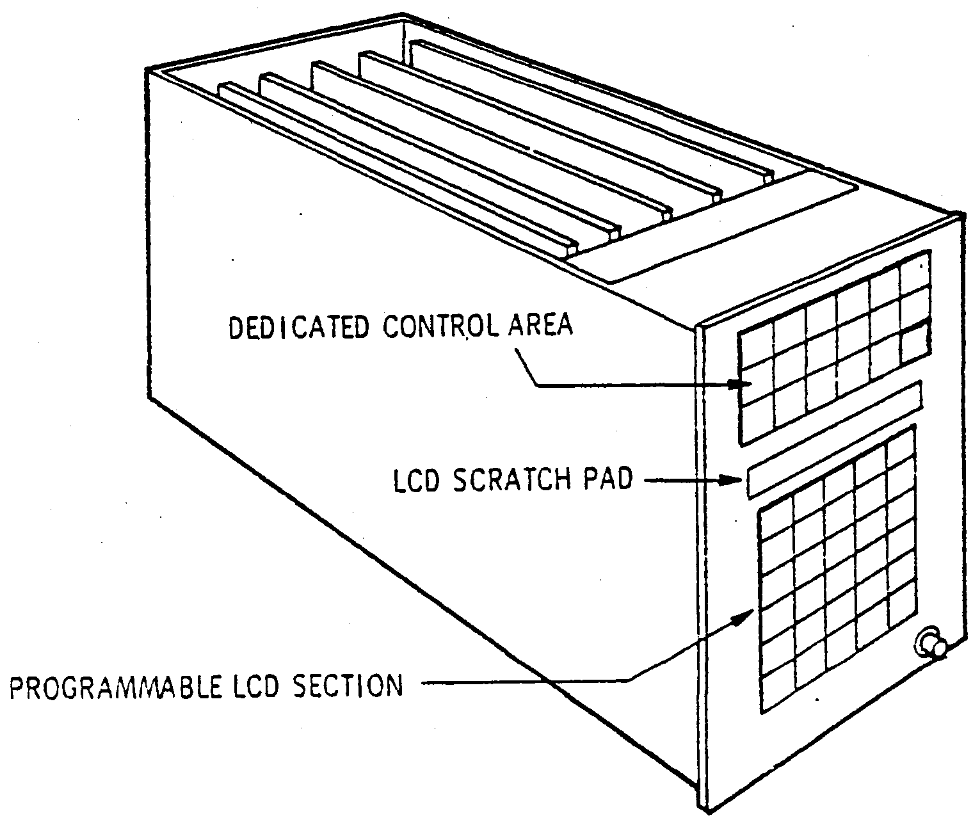


Figure III.10 - The General Electric Co. Integrated Control Panel

The integrated control panel is divided vertically into three sections. The upper section of 18 switches always displays the same labels, which are the various selectable modes such as CHECK LIST, COMM and NAV. The middle section is a 2-line by 30-character display used to display prompts or a selection log. The bottom section is a liquid crystal display (LCD) with a capacitive membrane touch pad overlay for 30 switches. When a mode is selected on the upper set of switches, the available options appear on the lower set of switches and the selection is logged on the center "scratchpad" area. A tree structure procedure or paging can be used as required.

The LCD is monochromatic, using white characters on a black background, and can be read in light levels from 0.11 to 108,000 lumens/square meter (.01 to 10,000 foot candles). The characters are 5.1mm (0.2") high and are formed with a 5 x 7 dot pattern; the dot matrix resolution is 14 dots/cm (36 dots/inch) and 10 characters can be shown on each key.

NASA-LaRC and the U. S. Air Force are also in the initial stages of procurement for a flat panel multi-function keyboard possibly using LED matrix technology. A supplier has not yet been selected for that program.

Echo-Ranging Sonic Detection - The echo-ranging overlay system shown in Figure III.11 consists of two parts; a glass screen with integrated electronics mounted directly on the glass, and a separate digital controller which provides the processing and interface signals. Acoustic standing waves are generated by the piezoelectric transducers located along the two sides of the digitizing surface to sense the position of an object in contact with the glass. An acoustic standing wave (Rayleigh wave) travels along the free boundary of a solid, much like a ripple on the surface of a pond. A user's touch sets up echo signals in both directions which are interpreted as the coordinates of the touch point. The acoustic waves are reflected by the passive probe and are used in an echo ranging system to convert the time taken for the acoustic echo to return into distance information for the target. Resolution for an echo ranging system is related to the spacing along two adjacent edges of the transducer and receiver pairs.

Beam Interruption - A beam interruption overlay system (Figure III.12) uses scanning infrared beam technology. This technique does not place anything in the optical viewing path of the user; neither glass nor plastic covers the display face. IR-emitting diodes are mounted approximately 6.4mm (1/4 inch) apart along two adjacent sides of a rectangular frame which fits the display perimeter; photo detectors line the remaining two sides, producing a grid of infrared beams. The infrared beam broken by the user's finger corresponds to the coordinates of the touched point. The beam interruption system resolution depends on the spacing of the emitters and detectors.

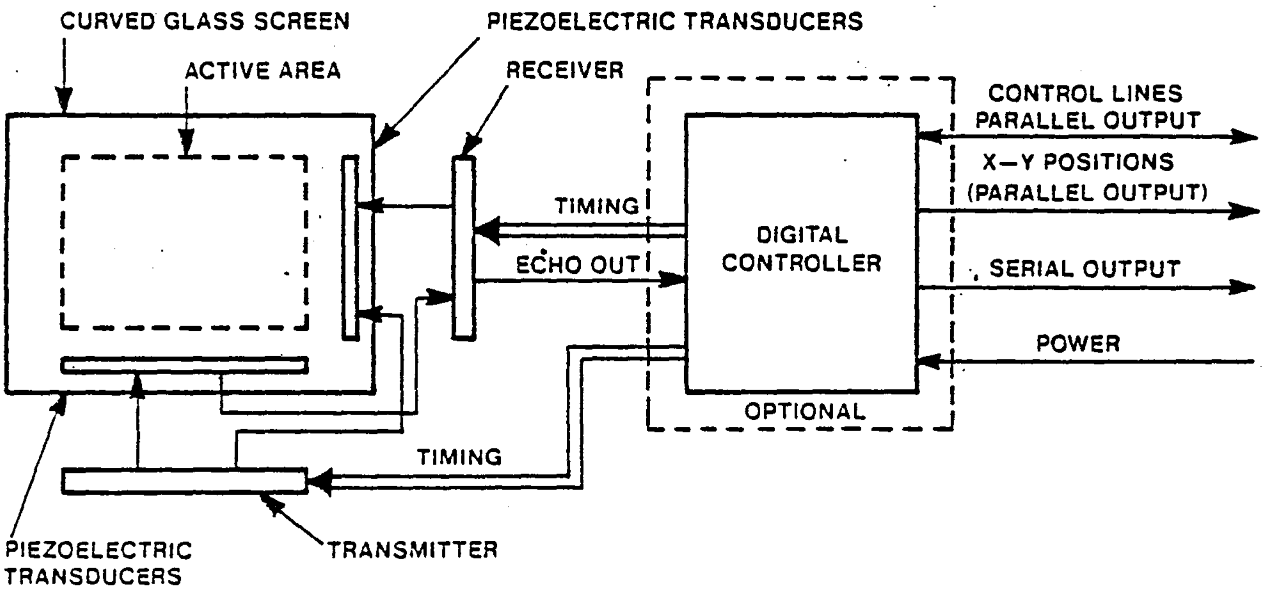


Figure III.11 - Echo Ranging Overlay

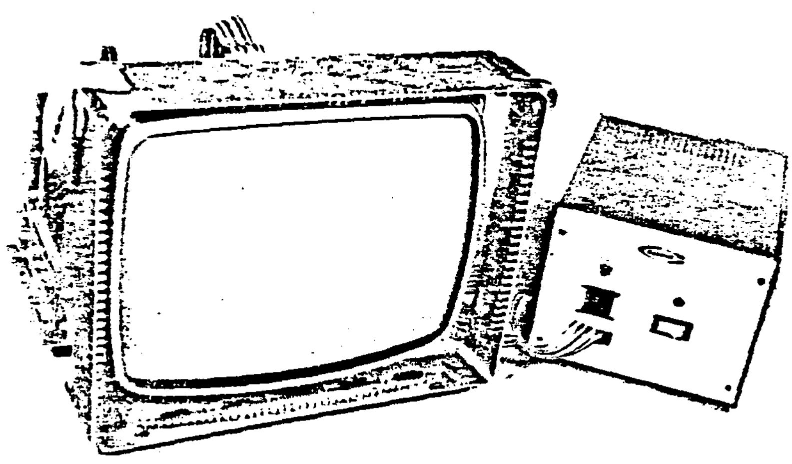


Figure III.12 - Beam Interruption System

Side Switches - Conventional pushbutton switches are utilized as line-select switches to create a programmable touch panel (Figure III.13). Blank pushbutton switches are mounted along the side of a CRT screen or flat panel. A computer-generated display appears on the display surface so that each option is aligned with a switch. An option is then selected by depressing the corresponding switch. The depressed switch may be illuminated while the corresponding legend is highlighted to give the required feedback.

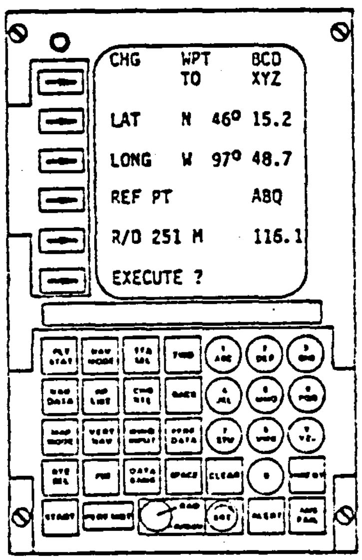
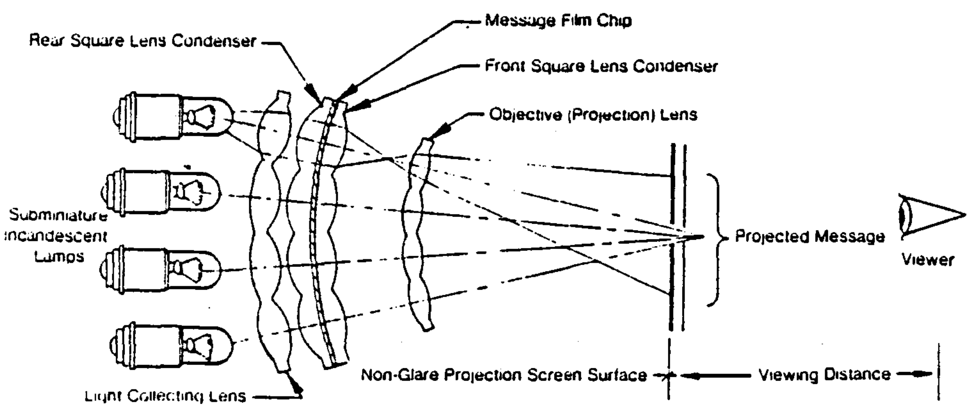


Figure III.13 - Side Switches for Line Selection

Rear Projection Switch Module - Multi-legend, rear projection, switch modules (Figure III.14) consist of light sources, light-collecting lenses, a storage medium for multiple messages, a color filter, and a viewing screen. Projection readouts are capable of displaying with variable brilliance any image, color, message, or type style which is reproducible on film. Present

module capacity ranges from 12 to 48 discrete messages with a maximum character height ranging from 1.9 to 85.7 mm (0.076 to 3.375 inches). The average character brightness ranges from 41.3 to 687.6 lumen/steradian square meter (12 to 200 ft lamberts), depending on message densities and operational voltages.



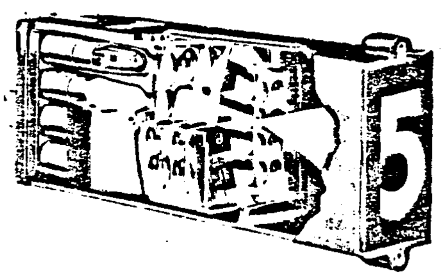


Figure III.14 - Rear Projection Switch Module

Mini-Displays/Switches - Miniature CRTs - One-inch CRTs (Figure III.15) are configured to form a touch panel arrangement. The CRT will display the desired legends and symbols under program control. Each CRT has a separate transparent switch actuator. Pressing the displayed command will actuate the appropriate switching functions to be performed.

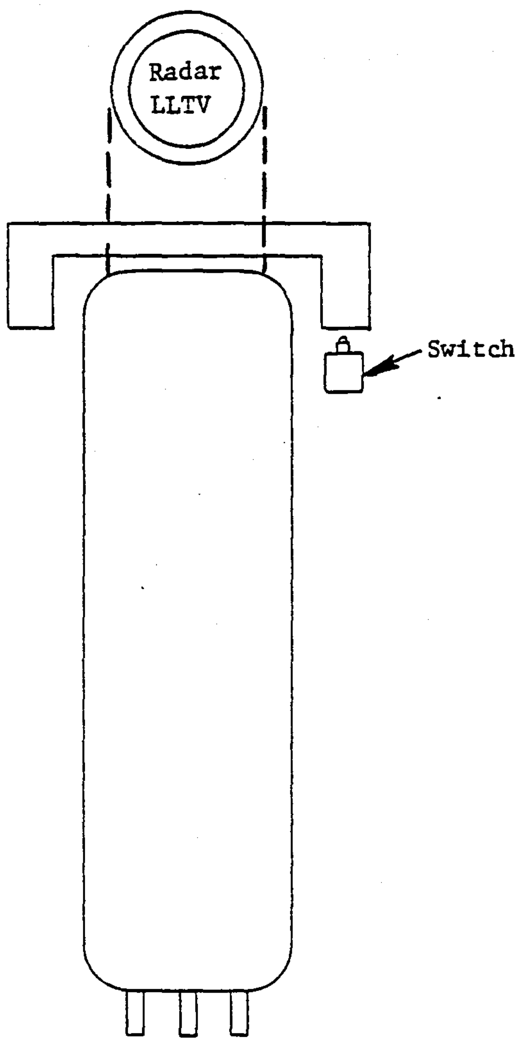


Figure III.15 - Miniature CRT Switch Module

Mini-Displays/Switches (Flat panel Displays)- This technology is similar to the mini-CRT concept described above except that individual flat panels (e.g., LED or LCD matrix-addressed displays) are used in lieu of mini-CRTs.

Cursor Control - A touch panel may be used to select options on a display, such as a head-up display or a projected picture, which is physically separated from the touch panel. A cursor on the display is placed by the desired option using the touch panel as shown in Figure III.16. To do this, the user touches the panel, observes the cursor position on the screen, then moves his finger until the cursor is correctly positioned. An auxiliary button or switch is required to signal that the cursor is beside the desired option.

Some Selection Considerations

The selection of a touch panel should be tailored to the specific application. Some of the considerations summarized in Figure III.5 are discussed in this section.

In some touch detectors the sensing elements cannot be placed directly against the display surface, and this separation between the touch detector and the display surface causes parallax. Parallax may be severe in a CRT because of its curvature and because the phosphor is behind the glass. The severity depends on the distance between the sensing and display surfaces, the viewing angle, and the separation between the options on the display surface.

Some types of touch detectors (e.g., the beam-interrupt type) are inherently flat. If such a touch detector is used with a CRT with significant curvature of the screen, the parallax will vary across the screen. The extent to which this may be troublesome

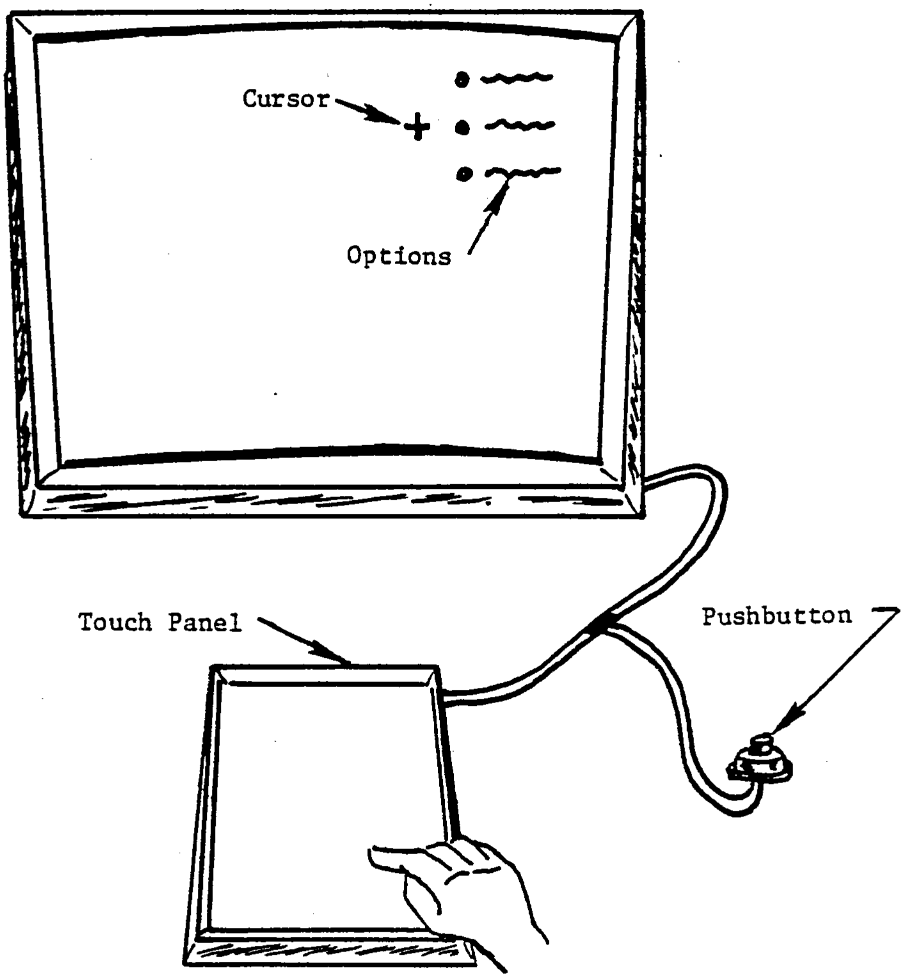


Figure III.16 - Option Selection Using a Touch Panel

depends on the curvature and the spacing of the options on the CRT screen.

Touch-actuated touch locators, in general, are transparent panels which cover the display surface. since some types (e.g., the voltage gradient substrate) have a significant amount of light attenuation, the display surface must have adequate brightness to overcome this attenuation.

Some touch panel types (e.g., the crosswire overlay) have rather coarse location detection, which is quite satisfactory for option selection but would not be satisfactory for position location without some special software features.

Human Performance Considerations

The human senses of positional memory, shape, and directional motion play a large role in the operation of conventional controls. For example, when driving a car we use the blinker light to signal a turn without taking our eyes off the road. We remember where the turn indicator control is located, its shape confirms that our fingers have touched the correct control, and we remember to push lever up for a right turn. Furthermore, we receive tactile feedback with the latching of the lever in the up position. The multifunction touch panel does not provide all these convenient clues. The user must read the legends or at least remember where the legend should appear on the display panel.

Touch panels generally do not have the inherent feel of actuation found in a snap-action switch. Some touch detectors (e.g., the beam interrupt type) merely sense the presence of a finger,

Other types (e.g., the capacitive membrane type) are actuated by a slight touch of the panel, and other types (e.g., the cross-wire overlay type) require significant pressure against the panel.

Although the basic touch-actuated panel does not have the positive feel of actuation, special features can be included to provide feedback. One approach is to build in a solenoid "thumper" into the case. When a selection is made on the panel, a distinct thump is heard and possibly felt. Some location assistance can also be provided by use of a plastic overlay which has holes, ridges, or elevations which correspond to the selection points. Some panels simply produce a "beep" for audible feedback each time an input is made.
Visual feedback can be provided by highlighting the selected option on the display surface by flashing, underlining, or brightening it. An additional "execute" square must then be actuated to complete the selection, or the activity can be cancelled.

Reliability

Time and budget limitations did not permit a thorough study of the reliability of touch panels. Therefore only general comments are given which summarize some relevant considerations.

With a few exceptions, touch panel components are not inherently reliable. This is principally because most equipment has been developed for the office or laboratory environment. Most systems have not been designed to operate under severe vibration and elevated temperatures and reduced atmospheric pressure. Two

exceptions are the beam interruption and line-select side switch types which have been ruggedized and military-qualified.

Several types of touch panels utilize CRTs as their display surfaces. CRTs tend to have problems with reliability and longevity. The larger sizes require higher voltage and power; the high voltage may cause excessive aging at reduced cabin pressures and indeed the CRT may fail to function completely due to cabin decompression. Also, the high power utilization causes a higher operating temperature which reduces reliability.

Shadow mask color CRTs require precise internal alignment and are not usually designed to withstand aircraft vibration. Rockwell-Collins has recently qualified small shadow mask CRTs for use in their electronic flight instruments, and other vendors are expected to follow suit. In general, experience is lacking for full color shadow mask CRTs in airborne use although monochromatic CRTs have been in common aircraft use.

Since electronic equipment has degraded reliability when subjected to temperature, vibration, and altitude extremes, commercially available equipment intended for laboratory use may not provide adequate reliablity and performance for aircraft use.

In general, components involving the simplest technologies and requiring the fewest manufacturing steps usually offer the most inherent reliability. Pressure sensitive and cross-wire overlays appear to offer reliability advantages because of their simplicity. However, there is some concern with these types regarding possible corrosion at the contacting surfaces. Special alloys can be selected to minimize this problem, and the contacting parts can be sealed in an enclosure.

In order for touch panel technology to attain the reliability and life necessary for transport aircraft use, a comprehensive reliability program including testing will be required.

CONCLUSIONS

The following conclusions are drawn from this study: The touch panel consists of two basic elements - the display surface and the touch locator or sensor. Most touch locator types can be used with either a CRT or flat panel display surface to form a touch panel.

Programmable touch panels suitable for simulator use in 1983 are commercially available today in the $3000 - $5000 range and others are under development.

Suitable types in common use are the beam interruption and the side switch line selector types; military-qualified versions of both of these types are available.

The voltage gradient type is also in use. It has the advantage that it is curved to minimize parallax when used with a large CRT. It causes some light attenuation but would probably be satisfactory for simulator use.

The crosswire type has the advantage of not attenuating the light from the display surface. However, it is not yet commercially available.

The CRT display surface has the advantage of a full color capability, complete flexibility of display including graphics, and adequate brightness. The flat panel display surface has the advantage of shallow depth and little or no parallax but is not available with programmable color. The only flat panel useful in high ambient light is the liquid crystal display.

Expected applications for touch panels include decision tree selection, page or long-list selection, limited point-selection on maps, and limited alphanumeric data entry. All touch types can perform option selection and limited data entry. Side switches, mini-displays, and rear projection switches are not suitable for point-location on maps.

The touch panel will be available for use as a major component in the integrated flight station of the 1990's. Since a single panel will perform the control function for a number of systems, it will probably be safety-critical and should have adequate backup.

APPENDIX A
VENDOR DATA

The following vendors supplied data that was instrumental in the writing of this report.

1. Boeing Technology Services (BTS)
   The Boeing Company
   PO Box 3707
   Seattle, Washington 98124

2. Bowmar Instrument Corp.
   Aerospace Division
   8000 Bluffton Road
   Fort Wayne, Indiana 46809
   (219) 747-3121

3. Carroll Manufacturing Company
   1212 Hagan Street
   Champaign, Illinois 61820
   (217) 351-1700

4. Clare Division, General Instrument Corporation
   3101 Pratt Boulevard
   Chicago, Illinois 60645
   (312) 262-7700

5. Control Data Corporation
   Peripheral Products Company
   PO Box 0
   Minneapolis, Minnesota 55440
   (612) 853-3165

6. Data Device Corporation (DDC)
   A Subsidiary of ILC Industries, Inc.
   Airport International Plaza
   Bohemia, New York 11716
   (516) 567-5600

7. Elographic, Inc.
   1976 Oak Ridge Turnpike
   Oak Ridge, Tennessee 37830
   (615) 482-4038

8. General Digital Corporation
700 Burnside Avenue
East Hartford, Connecticut 06108
(203) 289-7391

9. General Electric Company
Aircraft Equipment Division
Aerospace Electronic Systems Department
Utica, New York 13503
(315) 797-1000

10. Industrial Electronic Engineers, Inc. (IEE)
7740 Lemona Avenue
Van Nuys, California 91405
(213) 787-0311

11. Interstate Electronics Corporation (IEC)
707 E. Vermont Avenue
Anaheim, California 92803
(714) 635-7210

12. Licon Division, Illinois Tool Works, Inc.
6615 W. Irving Park Rd.
Chicago, Illinois 60634
(312) 282-4040

13. Magnavox Display Systems
Magnavox Government and Industrial Electronics Company
1313 Production Road
Fort Wayne, Indiana 46808
(219) 482-4411

14. Massachusetts Institute of Technology (MIT)
Department of Materials Science and Engineering
Cambridge, Massachusetts 02139

15. Maxi-Switch Company
9697 E. River Road
Minneapolis, Minnesota 55433
(612) 755-7660

16. The N/P Company
PO Box 127
5620 North Rosemead Boulevard
Temple City, California 91781
(213) 283-8854

17. Sierraciin/Sylmar Company
12780 San Fernando Road
Sylmar, California 913342
(213) 367-6184

18. Solid State Technology, Inc.
Wilmington, Massachusetts

19. Stanford Linear Accelerator Center (SLAC)
Stanford, California

20. TSD Display Products, Inc.
Megadata Corporatioin
35 Orville Drive
Bohemia, New York 11716
(516) 589-6800

APPENDIX B - TOUCH PANEL TECHNICAL DATA

This appendix lists some technical data about each of nine specific touch panel configurations which are currently available or which are in advanced development as shown in Figure III.6 The data is presented as it is given in available literature, and no attempt is made at uniformity.

Carroll Manufacturing Company

Touch Input System

1. Beam interruption technology
2. CRT display size: 12 to 19 inch diagonal
3. Resolution: 40 X 24 to 56 X 48 depending on screen size
4. All solid state construction
5. Microprocessor control
6. RS232 interface

Elographic, Inc.

E270 Transparent Pressure-Sensitive Sensor

1. Pressure - sensitive overlay
2. Unlimited programmability
3. Resolution: 0.003 inch
4. Curved glass sheet coated with a transparent resistive substrate and a plastic cover sheet backed by a transparent conductive layer.
5. X and Y encoding hardware
6. Light attenuation is caused by resistive substrate

General Digital Corporation

Vue Point (Touch Input Panel)

1. Beam interruption technology
2. Software selectable up to 240 touch-sensitive areas
3. RS232 compatible
4. 12 lines X 40 characters gas plasma flat panel display
5. Small - lightweight - portable
6. Multiple display buffers permit immediate screen updating
7. Automatic screen refresh
8. Switch selectable protocol and display option

General Electric Company

Integrated Control Panel

1. Capactive membrane technology
2. LCD flat panel technology with transparent switch panel
3. Readable in ambient light from 0.01 to 10,000 ft-candles
4. White characters on black background
5. Dot matrix density --- 36 dots/inch
6. 30 programmable touch actived legends
7. 60 character scratch pad
8. MIL-STD-1553B compatible
9. Viewing angle greater than 45 degrees

IEC

Model PD 3000

1. Beam interruption technology
2. Panel life: 10,000 hours
3. Panel size: 12.25" X 12.25"
4. Active display area: 8.55" X 8.55"
5. Resolution: 60 elements per inch
6. Brightness: 60 fl
7. Contrast ratio: 25:1
8. 85 character/line, 51 rows plasma panel
9. RS232C and parallel data output
10. 256 touch-sensitive positions

IEE

Rear Projection Switch Module

1. Rear projection technology
2. Limited multiple legends capability: 12 to 48 discrete messages
3. Programmable
4. Rated lamp life: 10,000 - 40,000 hours
5. Maximum operating tempeature: 85 degrees C
6. Character size: 0.076" to 3-3/8"
7. Average brightness: 12 to 200 ft-lamberts

Maganavox Display Systems

Model 28 Touch Panel for ORION-60 Plasma Display

- Beam interruption technology
- Optical distortion: none
- Plane of touch sensitivity: 0.2 inches above screen surface
- Touch sensitive matrix: 16 X 16
- Beam spacing: 0.532 inch
- Local indication: audio tone

Massachusetts Institute of Technology

Enhanced Input Terminal

- Crosswire overlay technology
- Two video monitors - one for display and the other provides keyboard inputs
- Vertical and horizontal crosswire spacing of 3/8"
- Crosswire matrix 20 X 30

TSD Display Products, Inc.

Touch Screen Digitizer

ho ranging technology

solution: adjustable from 0.05" to 0.15"

gh sensitivity

.tputs: 8 bit parallel TT1 data, RS232C

T display size: 15-inch diagonal. Other sizes available on
quest.

.sceptible to damage due to scratches on surface.

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	11. Contract or Grant No.: NAS1-15546
12. Sponsoring Agency Name and Address: National Aeronautics and Space Administration, Washington, DC 20546	13. Type of Report and Period Covered: Final Report, July 1979-January 1980
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15. Supplementary Notes

Langley Technical Monitor: Leonard V. Clark

16. Abstract The transport aircraft of the 1990s will use a number of new systems including MLS, 4-D Nav, CDTI, and DABS that will improve efficiency and safety. They also, however, give rise to new problems in the design of aircraft and aircraft simulators. This report investigates two of these problems--inter-equipment data transfer, both on board the aircraft and between air and ground; and crew-equipment communication via the cockpit displays and controls. Inter-equipment data transfer is discussed in Chapter I in terms of data bus and data link requirements. Crew-equipment communication is discussed in Chapters II and III regarding the availability of CRT display systems for use in research simulators to represent flat-panel displays of the future, and of software-controllable touch panels.

Chapter I, a brief investigation of Data Bus and Data Link requirements, showed that the presently defined ARNIC 429 and 453 data buses are adequate for all expected requirements for intra-aircraft data flow. MIL-STD-1553B multiplex buses will accommodate the basic equipment data flow on a single set of redundant buses, but will require separate buses for such wide-band signals as radar video. Chapter II contains a survey of large-screen color Cathode Ray Tube (CRT) graphics display systems and components that might be suitable for a multi-function cockpit display for simulator or laboratory use. In Chapter III, the results of a survey to determine the availability of software-controllable touch panels for use in flight station simulators are reported. Applications considered were simple option selection, decision tree option selection, paging or long-list option selection, alphanumeric data entry, and point location on maps. Touch panels are also discussed in terms of their two basic elements, the display surface and the touch locator.

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